REPORT

NO. LED-470-4 DATE: 15 July 1963

LTA-8 AND LTA-9 PRELIMINARY DESIGN
SUMMARY REPORT:
INTEGRATED SYSTEM DYNAMIC TEST
AND EVALUATION VEHICLES [U]

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1. INTRODUCTION

1.1 PURPOSE

The purpose of the Grumman Lunar Landing Test and Evaluation (LLT&E) program is to provide a means for integrated ground and flight testing of all LEM subsystems under conditions which allow repeated system operation, post-test examination of components, and systematic upgrading as required. The program will afford the opportunity for gaining operational experience and confirming LEM system operation prior to actual manned lunar flight, particularly with respect to the landing phase of the LEM mission.

This report presents the results of a preliminary design study directed toward determining the most effective method of using two LEM Test Articles, LTA-8 and LTA-9, in support of the program objectives. Also described in the report are the contributions which can be made to this program by two existing NASA lunar landing research programs as well as the currently programmed LEM Test Articles, LTA-1 through LTA-7.

In this introduction, the background leading to submittal of this report is first presented, the objectives of the preliminary design study are next briefly described, the scope of the effort undertaken to achieve these objectives is then reviewed, and finally the contents of the report are outlined.

1.2 BACKGROUND

On 12 April 1963, GAEC presented at MSC the results of a feasibility study carried out under item 3 (e) of enclosure 2 to NASA, MSC letter of December 19, 1962, W. F. Rector III. The primary requirement stipulated under item 3 (e) was to "conduct conceptual design of free flight vehicles for terminal approach, hover, and landing tests". As a consequence of this presentation, GAEC was requested Reference (1) to carry out a two-part preliminary design study concerning the use of atmospheric flight vehicles in the LEM program.

Chronologically, the first task was the "investigation of the use of LEM subsystems on components and design data and technology in the Flight Research Center (FRC) and Langley Research Center (LRC) lunar landing programs to increase their fidelity and applicability as regards LEM development". Results of this task were presented in Reference (2), which was forwarded to MSC on 16 May 1963 in accordance with the requested submittal date.

The second part of the preliminary design study task required that technical, schedule, cost and manpower information be established in the following areas:

A. Minimum modification and usage of LEM test articles for atmospheric test/flight modes. The preliminary design phase was to include, but not be limited to, study in the following categories:

1. Modifications to LEM equipment and structure.
2. Modifications to propulsion and reaction control systems.
3. Methods of extending flight duration.
4. Restrained and free flight safety provisions.
5. Capability for astronaut flight experience in hover and touch down.
6. Ground Support Equipment (GSE) requirements.

B. Integration with LEM ground and flight test programs considering:

1. Capability to achieve both the LTA-8 and LTA-9 mission goals.
2. Number of vehicles required.
3. Ability to complement other ground and flight test programs.

Requested submittal date for this task was 15 July 1963.

1.3 TEST OBJECTIVES

The test objectives which form the basis for the preliminary design tasks cited above are derived from consideration of the LEM landing sequence. The landing trajectory is initiated at the pericynthion of the LEM transfer orbit and terminates at lunar touchdown. Three modes of operation are used during the descent.

The initial powered descent employs programmed vehicle attitude control and constant descent engine thrust (at near-maximum thrust level) to bring the vehicle from the 50,000 foot pericynthion altitude to an altitude of 16,000 feet approximately 20 nautical miles from the touchdown area.

The final powered descent and flare, using proportional navigation with closed loop control of both vehicle attitude and thrust, brings the vehicle to a point 1000 feet from the touchdown area in range and altitude with the proper initial conditions for terminal descent. Vehicle attitude changes during both phases consist of gradual rotations about the pitch axis.

The terminal descent is accomplished manually, with the astronaut in control of both vehicle attitude and thrust. An initial rate of descent and forward velocity is established and then adjusted as required to hit the landing spot within the vehicle touchdown velocity limits (5 and 10 feet per second for horizontal and vertical velocity respectively).

In the first two phases, all subsystems are operative and are subject to the vibration induced by operation of the descent engine over a wide thrust range, from near-maximum to hovering thrust. Vehicle attitude changes, however, are gradual and confined essentially to a single plane. Vehicle velocity during these phases is well beyond the capability for atmospheric simulation.

The primary testing requirement in this case is the confirmation of integrated system performance with all subsystems functioning in the presence of descent engine and reaction control system operation. Test objectives in this category include the determination of:

* Vibratory response of combined LEM subsystems over the full range of descent engine thrust.

* Thermal and electrical interaction induced by the operating subsystems.

* Distribution of mechanical loading within the system.

* Electrical switching, transients, voltage regulation and power peaks throughout the interconnected subsystems.

* Effect of cumulative operation on system performance.

The terminal descent phase involves manned control of vehicle attitude and engine thrust, with the requirement for precise maneuvering to touch down at a pre-selected spot within the landing velocity constraints. Two semi-automatic control modes (attitude hold or attitude command) are available to the astronaut during this phase. In addition, a direct mode of control is available as a back-up. Velocities encountered during this phase are low. (Grumman Hover and Landing Simulator results indicate a maximum of 20 to 30 feet per second).

Here the primary test objectives are:

* Confirmation of vehicle dynamic response in all control modes with man in the loop.

* Evaluation of flight control system (FCS) operation including engine gimballing for trim.

* Evaluation of landing radar, inertial measuring unit (IMU), and flight display performance during the terminal descent.

* Capability for near-operational experience and familarization in the terminal descent phase of the mission.

Our preliminary design effort has been directed toward determination of the most effective means of achieving these test objectives in an earth environment. The scope of this effort is outlined in the following section.

1.4 STUDY SCOPE

1.4.1 Restrained Firing

The test objectives associated with the first two phases of the landing trajectory are amenable to restrained firing, since vehicle attitude changes are gradual and confined to a single plane. To confirm satisfactory integrated system operation and to uncover possible subsystem interaction, however, a near operational environment is required.

A comparison has been made of atmospheric firing versus firing in a partial vacuum from the standpoint of LEM equipment modifications required and the resultant changes in LEM operational characteristics. Use of the propulsion system test facility at the White Sands Missile range has been reviewed for compatibility with the overall LEM development schedule. Timeliness of LTA-8 system testing in the restrained firing mode has also been explored with respect to support of LEM-5, the first manned vehicle to undergo space flight.

Finally, the potential use of LTA-5 (propulsion development and qualification vehicle) for system test in lieu of LTA-8 has been investigated. The impact of this approach on the propulsion system development schedule has been assessed from two standpoints: the additional time required for installation and check out of equipment not presently programmed for LTA-5, and the possible increase in test cycle time attributable to additional system checkout requirements. (See Appendix J).

1.4.2 Dynamic Test

Both tethered and free flight dynamic testing have been investigated as a means of confirming LEM system operation in a dynamic regime during the terminal descent. The initial task in the area, common to both approaches, has been the determination of subsystem modifications required to achieve atmospheric operation and the consequent changes in subsystem performance. Additional tasks, pertinent to either tethered or free flight operation, are discussed below.

1.4.2.1 Tethered Flight

Tethered flight capability to satisfy dynamic test objectives has been investigated from the standpoint of flight envelope restrictions and cable force-feedback due to vehicle control inputs. The frequency content of LEM response to pilot input was measured on the GAEC Hover and Landing Simulator and compared to Langley tethered facility analog data to determine possible coupling between the two. Operational aspects of using the Langley LLRF for LTA-9 tethered operation have also been explored. Included in this category are: the capability of this facility to accommodate toxic hypergolic propellants, the ground support equipment and facilities required to support LEM operation, and the climatic conditions (wind direction and velocity, rainfall, lapse rate, etc.) which could have an effect upon attainable testing frequency. Similar data pertaining to WSMR has been compiled for purposes of comparison.

Another approach to tethered operation, that of using a helicopter as the means of support, has been investigated as a means of extending the flight test envelope. Test modes considered have included:

<u>A simple carry</u>, where the helicopter is used in a complementary role with the gimbal-mounted vehicle suspended beneath and "towed" through a pre-programmed flight path to provide Navigation and Guidance Subsystem flight checks not attainable on a fixed gantry.

<u>A "state of the art" carry</u>, in which the helicopter assumes the role of overhead follower and follows the gimbal-mounted vehicle motion by using cable angle and tension sensing as inputs to its automatic control system. Technology for this approach is based on the sonar coupler, drag-line coupler, and tether coupler systems developed by Sikorsky Aircraft (Reference 3).

<u>A system providing relatively precise following</u> of vehicle motion by the helicopter using cable angle and tension sensing at the supporting cable-gimbal junction point. (Reference 4).

In connection with the helicopter tether approach, the helicopter performance, cable force-feedback, and rotor down wash effects have been investigated. Potential use of a helicopter tether as a complement to fixed tether testing and also as the sole means of testing (precise following) has been compared from both the test and operational standpoints. The determination of helicopter tether development requirements and relative costs, however, is beyond the scope of this report.

Preliminary design of a gimbal system patterned after that employed on the Langley LLRF has been carried out and the inertias computed to determine their effect on vehicle control power. Mass properties of LTA-9 have been determined and means to maintain the gimbal axis through the vehicle center of gravity have also been explored. Atmospheric ground effects on the vehicle encountered in the vicinity of touchdown due to rocket exhaust efflux have been obtained using a 1/10 scale model of the vehicle descent stage with the appropriate thrust level simulated by nitrogen gas flow.

1.4.2.2 Free Flight

The atmospheric free flight capability and handling characteristics of a modified LEM with lift provided solely by the descent engine has also been investigated. The purpose here was to determine whether the additional vehicle modifications and safety hazards were warranted in terms of additional test benefits gained.

A preliminary design of a free flight vehicle has been carried out. Effort in this category has included:

* Review of subsystems and off-loading of all components not essential to free flight and/or test objectives.

* Preliminary design of an ejection seat installation and exit hatch.

* Preliminary design of a "work horse" landing gear including determination of semi-tread for landing gear stability in a one"g"environment and design of the gear itself.

* Computation of mass properties for the modified vehicle.

The mass properties were used to determine attainable flight duration. They were also inserted, together with the earths' gravitational environment, in the GAEC Hover and Landing Simulator. A short program has been carried out on the simulator to determine flying qualities and also to evaluate a pilot's ability to effect a safe landing within the limited flight time available. Experience derived from the simulator program was used to determine the suitability of the free flight vehicle for astronaut operational experience.

The capability of the vehicle to satisfy flight control system and navigation and guidance subsystem test objectives was assessed and compared to the capability afforded by tethered operation. The atmospheric ground effects for free flight take-off and landing operations were determined, again using model test with an appropriately scaled thrust level. Finally, the facilities required to provide safe take-off and landing capability were considered.

1.4.3 Test Plan

The information derived from the effort detailed in Sections 1.4.1 and 1.4.2 above was used to select the basic test modes most suitable for achievement of the Lunar Landing Test and Evaluation Program test objectives. An over-all test plan, utilizing the selected modes of operation and considering the use of existing test facilities, has been prepared.

In formulating a detailed test plan, it has become obvious that additional trade-offs arise when the locations of available test sites for restrained and tethered testing are considered. In the case of widely separated sites for restrained and tethered test operations, the cost of additional ground support equipment, instrumentation and checkout facilities and propellant storage provisions must be weighed against the cost of relocating or reconstructing the tethered facility to permit use of common equipment and facilities.

The potential use of a helicopter tether to supplement fixed-gantry tethered operation introduces additional trade-off factors. For reasons of safety (of both local populace and the test equipment), the helicopter operation would be located at WSMR. If off-site fixed-gantry tether testing is employed, loss of test time during vehicle transition (disassembly, shipment, re-assembly, and checkout) between test sites must be assessed in terms of both cost and affect on the LEM program.

Final selection of the site for tethered testing must include consideration of the cost implications of tethered facility relocation and is consequently beyond the scope of the present preliminary design effort. To aid in NASA evaluation of possible approaches, however, a series of alternative test plans have been prepared for purposes of comparison. These consider:

(a) Tethered operation at Langley only
(b) Tethered operation at Langley plus helicopter tethered operation at WSMR
(c) Concentration of all operations at WSMR.

A list of ground support equipment has been prepared for both separate test sites and a common test site. Also, as mentioned in section 1.4.2, comparative climatic data has been assembled for both Langley and WSMR.

1.5 REPORT CONTENT

The body of the report is devoted to a discussion of the program test objectives, test modes selected, and alternative test plans. Section 3 summarizes the over-all LLT & E program including the contribution of the currently programmed NASA lunar landing research programs and that of the present LEM ground test program. Section 4 describes the test objectives, constraints, test conditions, instrumentation requirements and the test plan pertinent to restrained firing. Section 5 discusses the same topics as applied to dynamic test of the integrated LEM systems, and presents alternative test plans for consideration by NASA. The body of the report concludes with a discussion of the reliability aspects of the proposed system test program and a description of GSE and facility requirements in Sections 6 and 7 respectively.

The technical data which has been generated in support of the preliminary design study is presented in a series of appendices, each dealing with a specific topic. Included here is a description of modifications required for atmospheric operation, a description of the test vehicles (LTA-8 and LTA-9), an analysis of tether cable dynamics and a preliminary evaluation of their effect on flight control system testing, results of a GAEC investigation concerning use of LEM propellants at Langley, a discussion of the aerodynamic and ground effects encountered in atmospheric operation, and the results of an investigation of the effect upon propulsion system development and qualification if LTA-5 is used as a restrained firing system test vehicle in place of LTA-8.

2. SUMMARY

2.1 CONCLUSIONS

The LEM ground test program does not presently contain provisions for testing in two basic areas:

* Integrated testing of the complete LEM vehicle with propulsion and RCS subsystems operative.

* Dynamic testing of the LEM vehicle with man in the control loop.

Within this framework, our primary conclusions concerning the role of LTA-8 and LTA-9 in the GAEC Lunar Landing Test and Evaluation program are that:

1. Capability for integrated testing of the LEM system with all subsystems functioning under near-operational conditions can best be achieved by operation of LTA-8 at the WSMR propulsion system altitude test facility under partial vacuum conditions.

2. Tethered operation affords the highest fidelity in handling characteristics, least modification to the basic LEM, and the safest approach to dynamic testing of the manned LTA-9 vehicle under conditions closely approximating the lunar terminal descent. Both fixed gantry and helicopter tethering are proposed.

3. Free flight of a modified LEM, using only the descent rocket engine to provide lift, does not offer sufficient capability in either dynamic system test or the opportunity for operational experience to warrant the additional pilot and vehicle hazard involved.

In the following sections, the justifications for these conclusions are advanced, the technical effort on which they are based is summarized, the system test programs utilizing the recommended modes of testing are briefly described, and recommendations for "action items" are made.

2.2 LTA-8 RESTRAINED FIRING SYSTEM TEST

Recommendation of the WSMR simulated altitude propulsion test facility for LTA-8 system test is based on the following considerations:

* <u>Minimum modification of the LEM vehicle.</u>
  LTA-8 requires no modification to basic subsystem hardware or structure other than removal of the landing gear and provisions for R&D instrumentation. Existing hard points, used to test-fire the LEM, will be employed.

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* Maximum fidelity of system operation.
Use of the partial-vacuum facility permits operation of the descent engine over its full thrust range. Isolation of the vehicle from facility structure by use of soft mounts insures that the engine-induced vibration will closely approximate that experienced by the operating subsystems during the powered descent from pericynthion to hover point. Vibration environment will be checked on LTA-5 (propulsion qual.) using dummy equipment. LTA-8 will confirm the equipment's ability to meet the environment.

* Use of existing facilities.
The WSMR facility provides the test stand, propellant storage, maintenance and checkout area, instrumentation blockhouse and safety provisions required to conduct the LTA-8 program. Additional checkout equipment will be required to accommodate the subsystems not provided for by the LEM-1 and currently planned LTA-5 programs.

* Additional test capability.
In addition to near-operational system test in the powered descent phase, the proposed test program calls for ascent stage test firings to confirm system operation during ascent from the lunar surface to rendezvous.

To provide adequate confirmation of subsystem operation during powered lunar descent and ascent, it is essential that the engine-induced vibration environment be accurately reproduced. Modification of the descent engine for atmospheric operation results in a maximum thrust decrease of 33% and a corresponding decrease in engine-induced vibrational displacement of 26% (Appendix B). The simulated altitude conditions afforded by the WSMR partial vacuum propulsion test facility are therefore considered necessary for the conduct of meaningful confirmation of system operation in the lunar environment.

2.3 LTA-9 DYNAMIC FLIGHT TEST

A major portion of our preliminary design effort has been devoted to a study of the relative merits of free flight versus tethered flight for dynamic system test. In the tethered flight mode considered, 5/6 of the vehicle's weight is sustained by a supporting cable and 6 degrees of freedom are provided by a gimbal arrangement plus an overhead follower (Section 3). In the free flight mode, vehicle lift is provided solely by the descent engine as modified for atmospheric operation.

2.3.1 Tethered Flight Dynamic Test

The recommendation that tethered flight be employed for dynamic system test is supported by the following considerations:

* Minimum modification to the basic LEM configuration.
Certain modifications, primarily affecting the propulsion, RCS and ECS systems, are required as a consequence of atmospheric operation and are common to both tethered and free flight (Appendix B). Beyond this, the tethered configuration requires adaptation of existing hard points to the vehicle-gimbal interface structure, use of landing pads suitable for repeated use, and replacement of existing crushable honeycomb shock absorbing cartridges after landing.

* Maximum fidelity of system operation.
Within the constraints imposed by atmospheric operation, the tethered vehicle affords the closest approach to both the LEM system configuration and lunar landing characteristics. (Appendices B and C).

- A full complement of operating subsystems plus a two man crew can be carried (vehicle not weight-limited).

- Rocket engine thrust levels are representative of the lunar terminal descent.

- Lunar tilt/acceleration coupling and representative touchdown characteristics are achieved by virtue of the cable supporting 5/6 of the vehicle's weight.

* Operational advantages.
Operational advantages accrue to the tethered approach as a consequence of the auxiliary support afforded by the cable.

- Flight duration capability exceeds that of free flight.

- Atmospheric ground effects (Appendix I) at touchdown are a minimum due to lower thrust, greater height of descent stage lower face above the terrain, and ability to "throttle chop" at a higher altitude.

- Pilot and vehicle safety is superior to free flight operation. The supporting cable permits immediate shut down in the event of incipient control system or propulsion malfunctions. The pilot can be removed immediately via a safety line in the event of fire or toxic propellant leakage.

Use of the tethered approach is not without disadvantages. The inherent inability of the overhead follower to track vehicle motion exactly plus the inertia of the cable itself gives rise to both steady state and oscillating horizontal cable forces which arise as a consequence of vehicle motion and are applied to the vehicle at the gimbal points. A preliminary analysis of force level and cable natural frequency based on Langley analog data (Appendix D) indicates that they are tolerable with respect to flight control system test objectives (Appendix E).

To avoid extraneous induced moments on the vehicle with changes in pitch attitude, the vehicle-gimbal interface structure must incorporate provisions for varying the pitch axis pivot point with respect to the vehicle such that the pitch gimbal axis continually passes through the center of gravity as it rises along the vehicle vertical axis during flight. Provision for initial trimming of lateral c.g. offset is also required. Design of a system to meet this requirement is discussed in Appendix C.

The gimbal structure inertia adds to the inertia of the vehicle for rotation about the X and Z axes. Vehicle response about all three axes is also affected by gimbal friction. A comparison of tethered vehicle control power with that of the basic LEM, taking into account gimbal inertia effects, is presented in Appendix C.

Use of a fixed gantry tethered facility (Section 3) imposes a relatively small (350' length x 165' height x 50' width) useable flight envelope for test operations. Our study has established that this volume is sufficient for dynamic test of the flight control system during terminal descent maneuvering to the limits of the restricted flight envelope, and will provide hover, touchdown, and operational experience for the pilot. Checkout of landing radar operation and the landing radar/inertial measuring unit updating interface under dynamic conditions requires a larger envelope. The use of a helicopter-supported tether to achieve this capability is discussed in Sections 3, 5 and Appendix K.

2.3.2 Free Flight Study Results

The recommendation to discard the free flight approach to dynamic system testing is based on the results of a series of studies carried out during the preliminary design effort. These results are discussed in Appendix H and are summarized below.

The ground effects model test (Appendix I) revealed a pronounced negative ground effect and unstable pitching moment when the vehicle is in close proximity to the terrain. At a scale thrust equivalent to a maximum atmospheric thrust of 7000 pounds, the download on the vehicle ranged from 800 to 1500 pounds as the height of the lower face of the descent stage varied from 4 feet to $2\frac{1}{2}$ feet above the terrain. Use of a perforated landing pad with provisions for ducting off the rocket exhaust would be required to counter this effect.

The Hover and Landing simulator studies, using three qualified pilots as test subjects, indicated flying qualities distinctly foreign to the lunar LEM due to differences in tilt/acceleration coupling and propellant burn-off. Attainment of safe touch-downs from a point 500 feet above and uprange of the touch-down area in a 60 second period was possible but difficult in the LEM semi-automatic control modes. Two subjects were not able to complete the task when the direct control (back-up) mode was used.

Flight duration is limited by the 7000# maximum atmospheric thrust capability of the descent engine. For a minimum empty weight of *4400 pounds a total flight time of 90 seconds including reserve is possible.

Extensive off-loading of equipment and structure is required to meet the above minimum weight. Major weight items removed are the ascent propulsion system, the LEM landing gear (replaced with shorter "work horse" gear), the meteoroid bumper structure and one crewman. Center-of-gravity shift as a result of inert weight removal requires addition of ballast for vehicle trim, which reduces flight duration to 82 seconds.

Additional structural modification in the form of an ejection seat installation and the previously mentioned workhorse landing gear is required to meet the requirement for pilot safety and repeated landings in a one g environment. Both items require additional tooling and development programs.

Capability for FCS testing at large pitch angles is compromised by the six-times greater horizontal acceleration resulting from a given tilt angle during flight in a 1 g environment. The combined effect of a lighter vehicle, higher thrust, and a maximum permissible aerodynamic velocity of 20 ft/sec. limit checkout of attitude hold capability to brief periods for the larger attitude excursions (on the order of 1/2 second for a vehicle weight of 6000 pounds and tilt angle of 30 degrees).

Hazard to pilot and vehicle imposed by free flight operation is greater than that of tethered flight. An incipient in-flight control or propulsion malfunction which could be countered by immediate system shutdown in tethered flight would result in pilot ejection and loss of the test vehicle in free flight.

Consideration of the factors cited above has prompted the conclusion that the free flight approach, although technically feasible, is inferior to the tethered approach from the standpoints of dynamic system test capability, fidelity of operational experience, and crew and vehicle safety.

* Based on LEM target weights

2.4 TEST PROGRAM

Definition of recommended test modes for LTA-8 and LTA-9 and the resulting vehicle modifications has been the pre-requisite for formulation of the overall test program described in Section 3. Generation of the detailed test plans for LTA-8 and LTA-9, described in Sections 4 and 5, has brought to light additional factors concerning implementation of the recommended test modes and selection of test sites. Summary descriptions of the test program and the factors which influence its implementation are presented in the following paragraphs.

2.4.1 Use of Existing Programs

The NASA lunar landing research programs being conducted at LRC and FRC will be used for early verification of LEM system design decisions relative to the terminal descent phase. Suitability of control power and damping characteristics, checkout of landing technique, and adequacy of visibility provisions and flight displays are examples of the type of information obtainable from these programs. They also offer a potential for early flight test of LEM flight control system and RCS hardware.

The LEM ground test program employs seven test articles to develop and qualify vehicle structural integrity, landing stability, environmental suitability, propulsion and RCS performance, and compatibility between subsystems and with the CM/SM, crew, and GSE. Test procedures and results which accrue during this program will support LTA's 8 and 9 in the same manner that they support the space-flight LEM vehicles.

System integration and environmental development data derived from LTA's 1 and 4 provide the background required for proper installation of qualified subsystems in LTA's 8 and 9. LTA-8 will use the propulsion test stand soft mount design, vehicle installation techniques, and test procedures established for LTA-5. The early LTA-5 qualification firings will provide the confidence in propulsion system performance necessary to the initiation of LTA-9 integrated test. The landing stability and structural integrity testing carried out on LTA's 2 and 3 will establish the basic structural capability of LTA-9 for tethered dynamic tests.

The test results of LTA's 1 through 7 will also provide a basis for data comparison in the areas of subsystem structural, vibratory and thermal response, as well as EMI. Correlation of LTA-8 data with that of LTA-7 will point up subsystem performance differences arising from the different test environments (See Section 3 for LTA-7 test conditions). The basic point here is that the LTA-8 and 9 integrated system test program supplements rather than duplicates the present LTA's.

2.4.2 Restrained System Test Program

The LTA-8 restrained firing test program (Section 4.0) commences with shipment of the vehicle to WSMR in December, 1965. Following checkout in the test stand, full duration firings will commence in February, 1966. A total of six complete mission cycle firings of the ascent and descent systems is provided in the initial test period. Two complete system tests will be completed prior to initiation of LEM-5 acceptance tests at GAEC. The test series will be completed two months before LEM-5 launch (based on a 40 day test cycle).

Subsystem thermal, electrical, and vibratory interaction will be monitored, and data gathered for correlation with previous test results. Simulated electrical inputs will be used to check subsystem response in a near operational environment. Post firing inspection will detect subsystem failures and permit systematic upgrading of LEM hardware.

A follow-on test program is planned to provide for possible contingencies and to support the LEM manned flight test program. The LTA-8 fabrication completion date of 30 June 1965 and the restrained firing test completion date of 30 September 1966 indicates capability of back-up for both LTA-5 and LTA-7.

Extension of the scope of the LTA-5 propulsion test program to include integrated system test has been investigated as an alternate to the use of LTA-8 (Appendix J). Two scheduling approaches were explored. The goal of the first approach was the attainment of earliest possible system testing. Here, available subsystems plus lines and plumbing were installed in LTA-5 at GAEC, four propulsion system test firings were completed at WSMR, the remaining subsystems installed, and systems testing initiated. Four propulsion and one system test firing was accomplished prior to the LEM-5 "cut-off date", (i.e. start of acceptance test at GAEC). This approach did not meet the propulsion test goal of 7 qualification firings prior to LEM-5 cut-off and was consequently considered unacceptable.

The second approach delayed installation of the remaining subsystems until completion of 7 qualification firings. The ensuing down time for equipment installation delayed initiation of system test until mid-June 1966, $4\frac{1}{2}$ months later than the proposed start of LTA-8 system test and $1\frac{1}{2}$ months after the LEM-5 cut-off date.

The use of a second vehicle solely for integrated system test affords significant advantages from both the scheduling and operational standpoints. Use of LTA-8 permits:

* Earlier availability of test results from both the propulsion qualification program and integrated systems test in support of LEM-5.

* Uninterrupted LTA-5 Phase II follow-on testing at a relatively rapid (23 days) test cycle time.

* Continued LTA-8 integrated system test in support of LEM-5 and subsequent manned space flights at the 40 day cycle time required for full-system test.

* Mutual on-site back-up capability to insure program continuity.

The use of LTA-8 does not require additional test facilities, ground support equipment, or qualified hardware over that which would be used on an uprated LTA-5. The basic hardware additions to the LEM program are one vehicle structure plus the propulsion and RCS subsystems. For the reasons cited above, it is recommended that the LTA-8 integrated system test vehicle be incorporated in the LEM ground test program.

2.4.3 Dynamic Flight Test Program

The LTA-9 dynamic test vehicle will be delivered to the test site in May of 1966. A two month period is devoted to assembly, equipment checkout and restrained firing to confirm system operation before start of tethered flight. Start of flight test occurs on Aug. 1966, three months prior to LEM-5 launch.

A nine-month flight test period is scheduled to cover the primary objectives of:

* Evaluation of integrated system dynamic performance.

* Evaluation of subsystem functions.

* Evaluation of potential subsystem malfunctions and degradations.

* Near-operational experience with man-in-loop.

The target date of 30 April 1967 for completion of primary test objectives coincides with shipment of LEM-9 to AMR. An eleven month follow-on period is scheduled for accumulation of operational experience and additional integrated systems test' in support of manned space flight operations.

Prior to the start of the operational test program, LTA-9 will undergo in-house testing to confirm suitability for tethered flight. Included in this category are: structural proof testing, static and dynamic ground tests of the gimbal system, drop tests, and a ground vibration survey. Development and checkout of the tether facility must be accomplished prior to completion of this in-house development period.

The study of the operational and technical aspects of achieving tethered flight has yielded the following results:

The Langley Tethered Facility can be used for dynamic system test within the bounds summarized in Section 2.3.1. The study described in Appendix G indicates that testing with LEM propellants can be conducted safely if the necessary precautions are incorporated, namely:

* Pavement and a water wash system for propellant spill containment beneath the gantry.

* Facilities for operating personnel designed for both fire and explosion hazards.

* Strict adherence to permissible wind direction, velocity, and atmospheric lapse rate as defined by the amount of propellant carried and proximity to inhabited buildings.

An extensive list of ground support equipment (GSE) is required at Langley for LTA-9 checkout and maintenance as well as test data acquisition (Section 7). Included in this category are maintenance test stations and special test units for subsystem repair and checkout, vehicle handling equipment, and propellant storage, handling, and transfer provisions. Equipment requirements duplicate those utilized for support of LEM's 1 and 2, LTA-5, and LTA-8 at WSMR.

Attainable test frequency at Langley is expected to be lower than that at WSMR based on the preliminary weather comparisons made in Appendix G. Key factors here are wind velocity and rainfall characteristics exhibited by each area. In addition, the presence of a positive lapse rate (inversion) at Langley would be sufficient to cancel a test flight based on criteria presented in Appendix G.

Another factor which bears on attainable test frequency at Langley is the proximity of public land to the test site. The impact of possible future private or commercial development of this land upon the tethered flight program must be ascertained.

The use of a helicopter for simple tethered carry of the vehicle through preprogrammed flight paths shows promise for providing the expanded flight envelope necessary for checkout of the radar altimeter/IMU interface under near-operational conditions. Extension of this approach to furnish automatic helicopter following of vehicle motion employing current technology (Appendix K) would provide the additional latitude required for change of direction during terminal descent, wave-off maneuvers, and radar altimeter/IMU operation in the presence of combined engine firing and vehicle attitude changes. The S-64 Flying Crane and the Vertol Chinook both possess the payload capability necessary for this operation.

The presence of rotor downwash implicit in this approach requires that sufficient forward velocity (approximately 10 ft/sec) be maintained to avoid downwash impingement on the test vehicle. thus, hovering flight can only be achieved in the presence of a slight headwind. In addition, the preliminary information received to date on attainable helicopter following capability is insufficient to establish that a LEM-type touchdown could be safely executed. As a minimum, however, helicopter tethering provides a valuable supplement to fixed gantry tether tests.

Safety aspects of the helicopter approach require that this operation be conducted at the WSMR test site. Efficient implementation of a test program utilizing both fixed gantry and helicopter tethering would necessitate the erection of an additional hovering facility at WSMR, using the existing Langley design.

2.5 RECOMMENDATIONS

Our preliminary design study has established the base for recommendations concerning both the need for near-operational atmospheric system test vehicles, and the most suitable test modes to be employed.

LTA-8 and LTA-9 fulfill critical functions which are not presently a part of the LEM Test Program: that of near-operational integrated system testing in support of the powered descent, terminal descent, and ascent to rendezvous phases of the lunar mission. Recommendations for achieving this capability are presented below.

2.5.1 Restrained Firing Recommendation

It is recommended that the LTA-8 vehicle be incorporated into the LEM Test Program for integrated system test in the WSMR propulsion system altitude test facility in accordance with the schedule presented in Section 4 of this report.

2.5.2 Dynamic System Test

It is recommended that the LTA-9 vehicle be incorporated in the LEM Test Program as a minimum-modified tethered flight vehicle to provide manned dynamic testing capability in a near-operational environment.

With reference to selection of an approach to tethered testing, the results of this report show that, from a technical and operational standpoint:

* Fixed gantry operation permits confirmation of the LEM flight control system as well as operational experience in maneuvering flight, hover and touchdown. The restricted envelope and steel gantry structure compromise testing of the radar altimeter and its interface with the IMU.

* An expanded flight envelope can be attained with a helicopter-tether. A simple carry will permit restricted-attitude testing of the radar altimeter/IMU with descent engine firing. Use of state-of-the-art helicopter following will provide near-operational test of these components plus expanded envelope testing of the FCS. Hovering flight and touchdown are compromised by rotor downwash effects.

* Concentration of testing at a single site is desirable to avoid duplication in facilities, GSE, and manpower.

* When weighed against use of the LRC facility, the conduct of tether tests at WSMR is advantageous from the standpoint of existing facilities, remoteness from populated areas, favorable climatic conditions, and the safety aspects of helicopter-tether operations.

Before a final selection of the method and site to be employed for tether tests can be made, the over-all cost pertinent to operation at the Langley LLRF or at WSMR must be evaluated, the full extent of helicopter following capability using current technology must be defined by detailed analysis and possibly a short demonstration test program, and the development cost and scheduling associated with the helicopter approach must be ascertained.

Accordingly, the following recommendations for initial action items relative to tether testing are offered for consideration by NASA:

1. Establish the cost of additional LEM GSE required to support an LTA-9 dynamic tether testing program at Langley; this effort is currently in process at GAEC.

2. Establish the cost of erecting components of the Langley tethered facility at WSMR. Determine possible cost savings if the existing Langley bridge system, dolly, and vertical hoist system are available for use at WSMR. (Availability required for 1 June 1966.) It is recommended that this information be furnished by MSC.

3. Establish the development cost, scheduling, and operational capability (in terms of following accuracy) of a helicopter-tether system employing currently available technology. It is recommended that this data be obtained by GAEC in conjunction with appropriate sources in the helicopter industry.

3. OVER-ALL TEST PLAN

The currently planned LEM test program is presented in Reference (5). Figure 1.15 of Reference 5 , reproduced here as table 3.1, indicates that the LEM terminal descent and touchdown phases of the lunar mission are not preceded by a similar mission phase development in which to gain near-operational system operation and flight experience. This Section summarizes the existing LEM ground test program and the NASA lunar landing research programs. It is shown that potential problem areas within the complete LEM vehicle which lead to degraded mission success, mission failure or loss of life if they are not uncovered prior to manned flight, particularly the lunar landing mission, can be investigated through dynamic testing of an integrated LEM system in an altitude firing chamber, LTA-8; plus a manned, integrated LEM vehicle capable of near-operational flight experience, LTA-9.

These vehicles will permit complete system testing under propulsion/RCS firing conditions. Each provides a unique capability. LTA-8 permits testing under a space simulated propulsion environment with the ability to thoroughly investigate the vehicle and its integrated subsystems after each test run. Tethered LTA-9 tests permit the gaining of operational flight experience, including malfunction and maneuvering experience too difficult, dangerous or costly to acquire under free-flight or space-flight conditions. Dynamic test confirmation in the latter part of the powered descent mission phase as well as the terminal descent phase will be accomplished with LTA-9.

The test vehicles discussed in this report are designed to supplement the currently planned LEM program by investigating the combined LEM system capability under propulsion and RCS firing conditions and LEM dynamics with man-in-the-loop. In order to derive maximum benefit from the lunar landing test and evaluation program these vehicle tests must be properly phased with the LEM program.

Figure 3.1 summarizes the integrated development forming the Lunar Landing Test and Evaluation Program. The figure shows the over-all LTA-8 and LTA-9 scheduling for accomplishing their respective test objectives. It also illustrates the relationship between potential use of the NASA lunar landing research vehicles, the proposed LTA-8 and LTA-9 test programs, and the manned LEM space flights.

3.1 SUMMARY OF THE EXISTING LEM GROUND TEST PROGRAM

The current LEM ground test program, summarized in figure 3.2, utilizes seven ground test vehicles to cover the areas of structural, propulsion, and system test. The equipment in each vehicle and the vehicle test applications are summarized in table 3.2 and are briefly described in this section. The contribution of these vehicles is assessed and additional test requirements are described.

3.1.1 LTA-1: LEM Integration

LTA-1 will be metal facsimile of LEM ascent and descent stages, capable of incorporating complete S & C, N & G, Crew Provisions, ECS, Instrumentation (R & D + Operational), Electrical Power, and Communications subsystems. Dummy RCS and Propulsion engines will be used. (Propulsion Subsystem will consist of prototype Rig P-3).

LTA-1 will be used at GAEC for installation and functional testing of the subsystems in correct geometrical relation to each other. Removable panels on the metal skeleton of LEM will facilitate tests and changes. Early evaluation of electromagnetic interference, ECS operation, and GSE also is planned.

3.1.2 LTA-2: Drop Tests

LTA-2 will be a LEM landing gear, attached to a representation of the descent stage structure, ballasted to LEM weight and balance. A series of drop tests to design critical landing conditions will be made at GAEC to prove the stability and strength of the gear before shipment to MSFC where Saturn IB and Saturn V booster vibration and shaker tests will be run. LTA-2 is the first out-of-plant delivery currently shceduled.

3.1.3 LTA-3: Structural

LTA-3 will consist of a prototype structure complete with landing gear and a prototype ECS to verify its structural integrity for LEM-1 - LEM-4 flights, but using ballast to simulate weight and location of all other subsystems and crew. Pressure and static tests for critical conditions, vibration and drop tests, and finally, failing load tests will be performed. These tests will qualify LEM structure for critical static and dynamic loads, demonstrate failing strength margins, determine structural stresses, stiffness and dynamic response characteristics of the structure itself and the equipment supported by structure, and verify analysis and design assumptions. All tests will be performed at GAEC.

3.1.4 LTA-4: Environmental Development

LTA-4 will be a complete LEM with all subsystems operational and, where feasible, qualified. Environmental development tests, to be conducted at GAEC, will consist of weight and balance, ambient acceptance, electromagnetic radiation interference, and thermal vacuum tests. In addition, vibration and drop tests will be run to complement those on LTA-3 and qualify the LEM structure for critical vibration and lunar landing conditions with functioning subsystem equipment. Referee fluids will replace the propellants and reactants in the onboard tanks.

Table 3-1 Relationship of LEM Flight Test Missions with Lunar Mission and the Effect of Component Failure

Key

Simulated:
- In lunar orbit
- In cislunar space
- In Earth orbit
- In suborbital flight

Component failure could:
- ■ Cause loss of life
- ▲ Prevent mission success
- □ Cause degraded mission success

Flight LEMS ↓ / Mission Phases →	Launch & Earth Orbit Injection	Earth Orbit	Translunar Injection	Transposition & Docking	Translunar Flight	Midcourse Correction	Crew Transfer	Lunar Orbit Injection	Separate LEM	LEM Attitude Control	Thrust to Sync. Orbit	Coast in Clear Orbit	Throttled Burn to Hover	Final Descent	Lunar Touch-down	Stage Separation	Lunar Launch	Ascent Thrusting	Clear Orbit Injection	Rendezvous	Dock	Crew Transfer	LEM Jettison
10	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	■	■	■	■	■	▲	■	■	■	□	□	□	□
9	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	■	■	■ (in lunar orbit)			▲	■ (in lunar orbit)	■	■	▲	▲	□	□
8	▲	▲	▲	▲	▲	▲	▲	▲ (in cislunar space)	▲	▲	■ (in cislunar space)	■ (in cislunar space)	■ (in cislunar space)			▲	■ (in cislunar space)	■	■ (in cislunar space)	▲	▲	□	□
6	▲	▲		▲	▲ (in Earth orbit)		▲		▲	▲	■ (in Earth orbit)	■ (in Earth orbit)	■ (in Earth orbit)			▲	■ (in Earth orbit)	■	■ (in Earth orbit)	▲	▲	□	□
5	▲	▲		▲	▲ (in Earth orbit)		▲		▲	▲	■ (in Earth orbit)	■ (in Earth orbit)	■ (in Earth orbit)			▲	■ (in Earth orbit)	■	■ (in Earth orbit)	▲	▲	□	□
3	▲	▲			▲ (in Earth orbit)					▲	▲ (in Earth orbit)	▲ (in Earth orbit)	▲ (in Earth orbit)			▲	▲ (in Earth orbit)	▲	▲ (in Earth orbit)				
1	▲ (in suborbital flight)									▲	▲ (in suborbital flight)		▲ (in suborbital flight)			▲	▲ (in suborbital flight)	▲					

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3.1.5 LTA-5: Propulsion

LTA-5 will be a LEM structural shell equipped with complete propulsion and RCS subsystems. Each subsystem will consist of feed system tankage, helium pressurization system, and the thrust chambers. Dummy masses and detailed instrumentation will be installed to check the equipment vibration environment. LTA-5 will be used to completely qualify the Propulsion Subsystem. Tests will be conducted at WSMR, and consist of test firings under simulated mission conditions. Complete mission will be accomplished, including starts, stops, off-nominal operations, throttling, and endurance runs.

3.1.6 LTA-6: Apollo Integration

LTA-6 will be a structurally complete LEM with landing gear, crew seats, and mocked-up crew compartment duplicating ingress and egress conditions. LTA-6 will be ballasted to LEM weight and balance. Erection and instrumentation of the vehicle will be completed by GAEC at NAA, Downey, where compatibility of LTA-6 and the CM/SM will be tested under flight vibration conditions. Support required for other Apollo tests involving the integrated LEM/CM/SM, will also be evaluated.

3.1.7 LTA-7: Environmental Qualification

LTA-7 will be a complete LEM except that substitute liquids will be used for the hypergolic propulsion and RCS fluids; liquid nitrogen will replace liquid hydrogen in the electrical power supply, while the fuel cells will be operated with externally supplied gaseous reactants, and ballast will replace all pyrotechnic devices. LTA-7 will be used at GAEC to establish the acceptance tests to be performed on each LEM prior to delivery, including weight and balance, electromagnetic interference, vibration, thermal vacuum and functional tests. At MSC, LTA-7 will be placed in the environmental chamber to perform environmental qualification tests including electromagnetic interference, vibration, thermal vacuum, subsystem intergration, and crew compatibility tests.

3.1.8 Additional Test Requirements

LTA's 1 through 7 provide coverage in the areas of structural environment and compatibility with ground support equipment, subsystems, CM/SM, and the crew. It is apparent from table 3.2, however, that operational testing of a complete LEM with all equipment functioning and the Propulsion and Reaction Control systems operative is not accomplished. LTA's 4 and 7, (environmental development and qualification) carry all equipment but simulate engine operation with shaker-induced vibration.

Table 3-2 Test Contributions; LTA-1 Thru -7

	LTA →	1	2	3	4	5	6	7
SUB-SYSTEMS	Structure	▲	▲	■	■	■	■	■
	G&C/N&G	■	Ballast	Ballast	■	▲/●	Ballast	■
	Crew Systems	▲	Ballast	Ballast	■	▲	Ballast	■
	ECS	▲	Ballast	Ballast	■	●	▲	■
	Ldg. Gear	●	■	■	■	●	■	■
	Instrumentation	■	Ballast	Ballast	■	▲	●	■
	Electric Power	■	Ballast	Ballast	■	▲	Ballast	■
	Propul/RCS	Inert	Ballast	Ballast	Inert	■	Ballast	Inert
	Communications	■	Ballast	Ballast	■	●	Ballast	■
STRUCT LOADS	Static			■				
	Drop		■	■	■	■ (Sep.)		
	Failing			■				
VIBR'N	Booster or CM/SM		■	▲	▲		▲	▲
	LEM Propul/RCS			▲	▲	■		▲
	Subsys Interaction				■	▲		■
NAT'L ENVIR	Thermal				■	▲		■
	Vacuum				■	▲		■
ELECT. LOADS	EMI { LEM	■			■			■
	EMI { LEM-CM/SM							■
	Electrical Load				■			■
COMPATI-BILITY	GSE	■						
	Subsystems	■			■			■
	LEM-CM/SM						■	■
	Crew						■	■
VEHICLE DYNAMICS	Angular & Linear { Accel							
	Angular & Linear { Velocity							
	Angular & Linear { Position							
	T-D Dynam Stability		■					
	Man-in-Loop							

■ Complete ▲ Partial or Simulated ● Omitted

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LTA-5 (propulsion development and qualification) provides the capability for propulsion and RCS operation, but carries only those portions of the LEM subsystems associated with propulsion test. Additional subsystems can conceivably be retrofitted to achieve integrated test capability. This approach, however, will compromise the basic objective of LTA-5; that of developing and qualifying the Propulsion Subsystem with flight weight hardware prior to acceptance testing of LEM 5 (see Appendix J).

It is also apparent that dynamic testing is provided only in the area of touchdown dynamics (LTA-2). The current test program affords no capability for dynamic testing of the LEM system with man-in-the-loop prior to manned space flight. As shown in table 3.1, the space flights themselves (prior to LEM-10) do not yield near-operational system experience in the critical terminal descent and landing phase of the mission.

In summary, two areas of testing are not covered by the present ground test program:

- Integrated operation of all LEM subsystems with Propulsion and RCS Subsystems operative.

- Dynamic testing of the LEM system with man-in-the-loop.

3.2 CONTRIBUTION OF EXISTING NASA LUNAR LANDING RESEARCH PROGRAMS

Two programs currently under development by NASA have direct application to the lunar landing mission. These are the Flight Research Center Lunar Landing Research Vehicle (FRC-LLRV) and the Langley Research Center Lunar Landing Research Facility (LRC-LLRF). Both programs, and their potential application to the GAEC Lunar Landing Test and Evaluation Program, are briefly described below.

3.2.1 Lunar Landing Research Vehicle (LLRV)

This vehicle, under development by Bell Aerosystems for FRC, is a VTO craft designed to provide lunar handling characteristics in an earth environment. The configuration (figure 3.3) consists of an open framework structure with the pilot seated forward and balanced by an aft-mounted equipment bay. A zero altitude-zero velocity ejection seat is provided for pilot safety. The landing gear is a symmetrical cruciform composed of 4 truss members arranged in an "X" position with respect to the vehicle longitudinal centerline. Lunar gravity simulation is provided by a double gimballed General Electric CF-700 turbofan engine which supports 5/6 of the weight of the vehicle via an automatic throttling system. Automatic compensation for aerodynamic forces and moments permits pseudo-vacuum handling characteristics. Pilot-controlled throttleable hydrogen peroxide lift rockets are used to simulate the descent rocket engine, and a hydrogen peroxide reaction control system is used for attitude control.

A variable stability autopilot provides capability for varying vehicle control power and damping to simulate a range of handling characteristics. Three of four controls modes used by LEM are provided; attitude hold, attitude command, and direct.

The vehicle can carry a pilot plus 200 pounds of research payload for 10 minutes with 2 minutes of lift rocket operation. Payload capability can be increased by off-loading rocket propellant. The vehicle has a ceiling of approximately 7000 feet MSL, V max of 70 ft/sec, and a maximum rate of descent of about 60 ft/sec. Start of flight test at FRC is scheduled for April 1964.

3.2.2 Lunar Landing Research Facility (LLRF)

The LLRF at Langley (figure 3.4) is an overhead crane structure 400 feet long by 250 feet high. Lunar gravity is simulated by an overhead servo-driven follower, which supports 5/6 of a suspended vehicle's weight via a cable system. The overhead system is slaved to vehicle motion to maintain the supporting cable near vertical during the flight. The follower plus a gimbal system in which the vehicle is mounted provides 6 degrees of freedom for vehicle motion in an operating envelope 350 feet in length, 165 feet high, and 50 feet wide. Maximum weight capacity of the tethered system is 20,000 pounds.

The LLRF program includes a research vehicle with a throttleable hydrogen peroxide engine and a hydrogen peroxide reaction control system. Control power variation and control mode capability are similar to that of the LLRV. Two-man capacity is provided with capability for installation of LEM flight displays and control as well as simulation of visibility characteristics. Availability of this facility is also scheduled for April 1964.

3.2.3 Application of NASA Programs to LEM Development

These programs have at least two areas of application to LEM development (see reference 2). The first area is that of early verification of LEM system analysis and system design decisions. Here their currently planned research programs can be directed toward:

- Selection of LEM control system handling qualities.
- Checkout of landing profiles and techniques.

- Operation in degraded control modes.
- Checkout of LEM visibility provisions during terminal descent.
- Checkout of display arrangements under near-operational conditions.

These facilities also provide the potential for early dynamic test of elements of the LEM Flight Control System (FCS). Here, the Stabilization and Control (S & C) and Reaction Control (RC) Subsystems and their respective controls and displays would be installed aboard one of the research vehicles.

Test objectives in this area are:

- Evaluation of control effectiveness in all modes.
- Confirmation of RCS logic, switching, and stability.

The larger flight envelope of the LLRV makes its use attractive for this purpose. Installation of the RCS aboard this vehicle (from the standpoint of physical compatibility and attainable torque-to-inertia ratio) is currently being investigated by the GAEC FCS group.

Two important needs are still left unfulfilled; namely confirmation of:

1. The response of the end-to-end or interconnected subsystems when exposed to LEM Propulsion and Reaction Controls inputs.

2. Manual control and experience with the combined LEM hardware under near-operational flight conditions.

These objectives can only be accomplished using complete LEM Test Articles.

The manned vehicle operational experience requires an LTA modified for atmospheric operations (see Appendix B). The vehicle will be in the lunar landing configuration and does not require the operation of ascent propulsion.

In order to derive maximum benefit from the end-to-end connected subsystem tests, an LTA configuration capable of ascent engine firing as well as descent engine operations is required. To expose the onboard subsystems to a near-operational environment, the mechanical and acoustical power input should duplicate that of the LEM space operational environment. Utilization of the WSMR-PSDF altitude test stand would provide the capability to operate the test vehicle under the most beneficial conditions.

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3.3 TEST OBJECTIVES OF LTA-8 AND LTA-9

While the currently planned LTA vehicles make a strong contribution to the over-all test, none of them provides for investigation of:

1. Vehicle Dynamics
2. Man-in-the-Loop
3. End-to-End connected subsystem performance in the presence of LEM propulsion and RCS environments.

The over-all test objectives of the integrated system tests of LTA-8 and LTA-9 are:

1. Performance evaluation, including parameter changes and degraded subsystem operations.

2. Diagnosis of failure modes based upon operational experience,

    a. based upon successful operations, design and analysis assumptions will be confirmed,

    b. based upon failure detection, fixes will be developed.

3. Verification of the dynamic response of integrated subsystems in near-operational environments.

4. Establish or confirm serviceability, maintenance, and replacement routines based upon near-operational experience. Similarly, safety and checkout procedures will be confirmed and updated.

Study of the existing test plan for the LTA-5 propulsion qualification vehicle shows that LEM propulsion qualification with complete LEM subsystems onboard would compromise the LEM program schedule; particularly the launch date of LEM 5, the first manned LEM. In Appendix J, the results of an investigation which supports this conclusion are presented.

Utilization of LTA-8 as the integrated system restrained firing test vehicle would leave LTA-5 free for propulsion qualification. The proposed design, manufacture and acceptance test schedule for LTA-8 (figure 3-1) would result in the LTA-8 integrated system firing tests starting after Propulsion Qualification is well along. In addition to providing a natural build-up from propulsion qualification to the effect of propulsion on operating subsystems phase, LTA-8 initially serves as a backup to LTA-5. The end-date for accomplishing the primary LTA-8 objectives corresponds to the launch preparation period for LEM 5.

The LTA-9 flight tests are scheduled to commence in the Summer of 1966, coinciding with the attainment of LTA-8's primary test objectives. The end-date for accomplishing the LTA-9 primary test objectives corresponds to initiation of the checkout period for the LEM 9 lunar "concept check" mission, the Summer of 1967.

The utilization of equipment and facilities to support the LTA-8 and LTA-9 vehicle operations is shown in figure 3.5. LTA-8 is straightforward since operation at the WSMR Propulsion System Development Facility is the most practical course of action. The schematic flow diagrams for tethered operations, however, indicate that the scope of the logistics effort for LTA-9 is highly dependent upon the test site location as well as the tether method (i.e., helicopter or fixed facility). Figure 3.6 presents a comparison of operational test schedules of the various tethered test methods studied and illustrates the time penalty paid for shipment between test sites at WSMR and LRC. Later in this report, the operational aspects of these different methods are discussed in detail.

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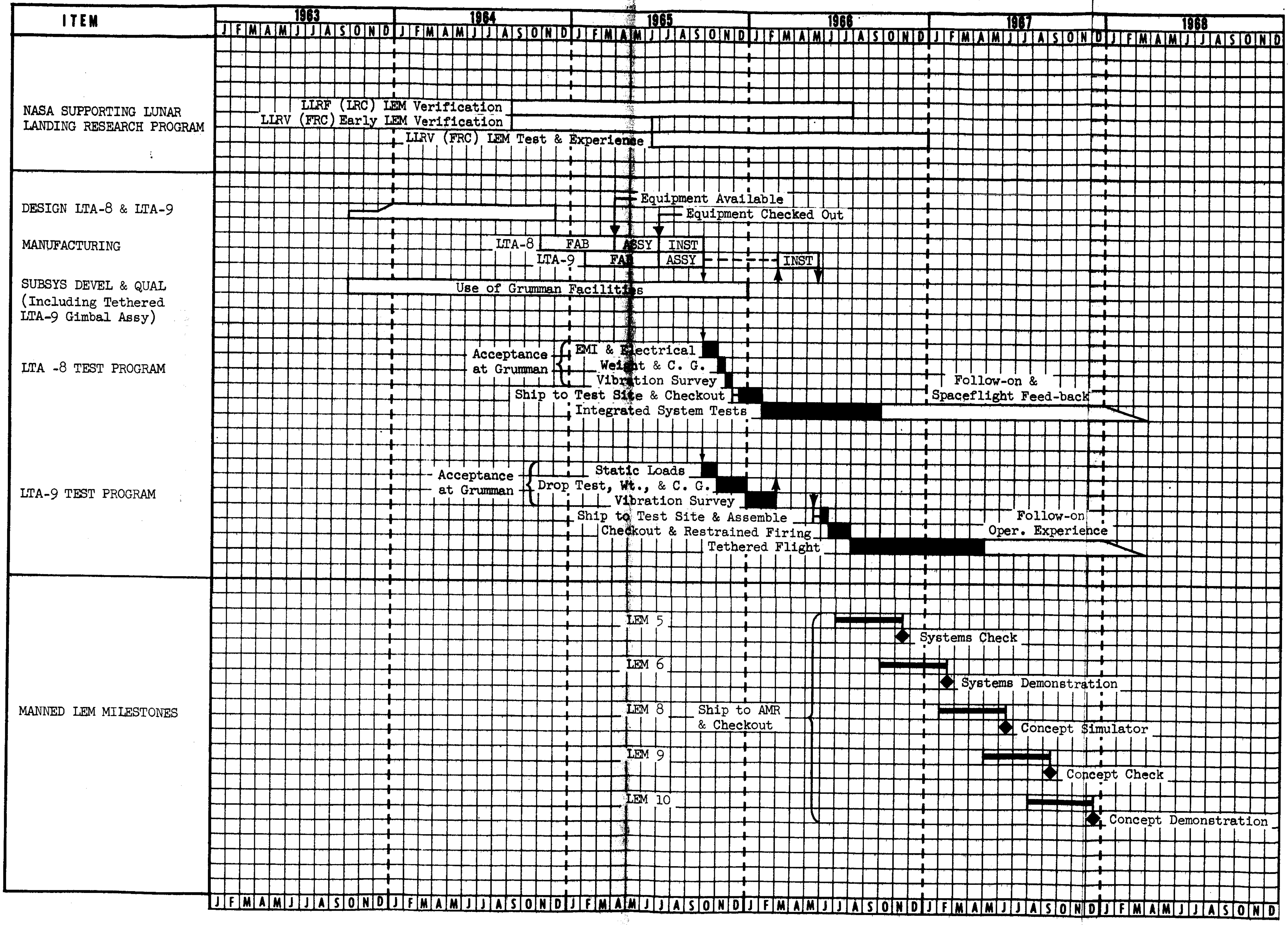

Fig. 3-1 Over-All Program Schedule

[redacted]

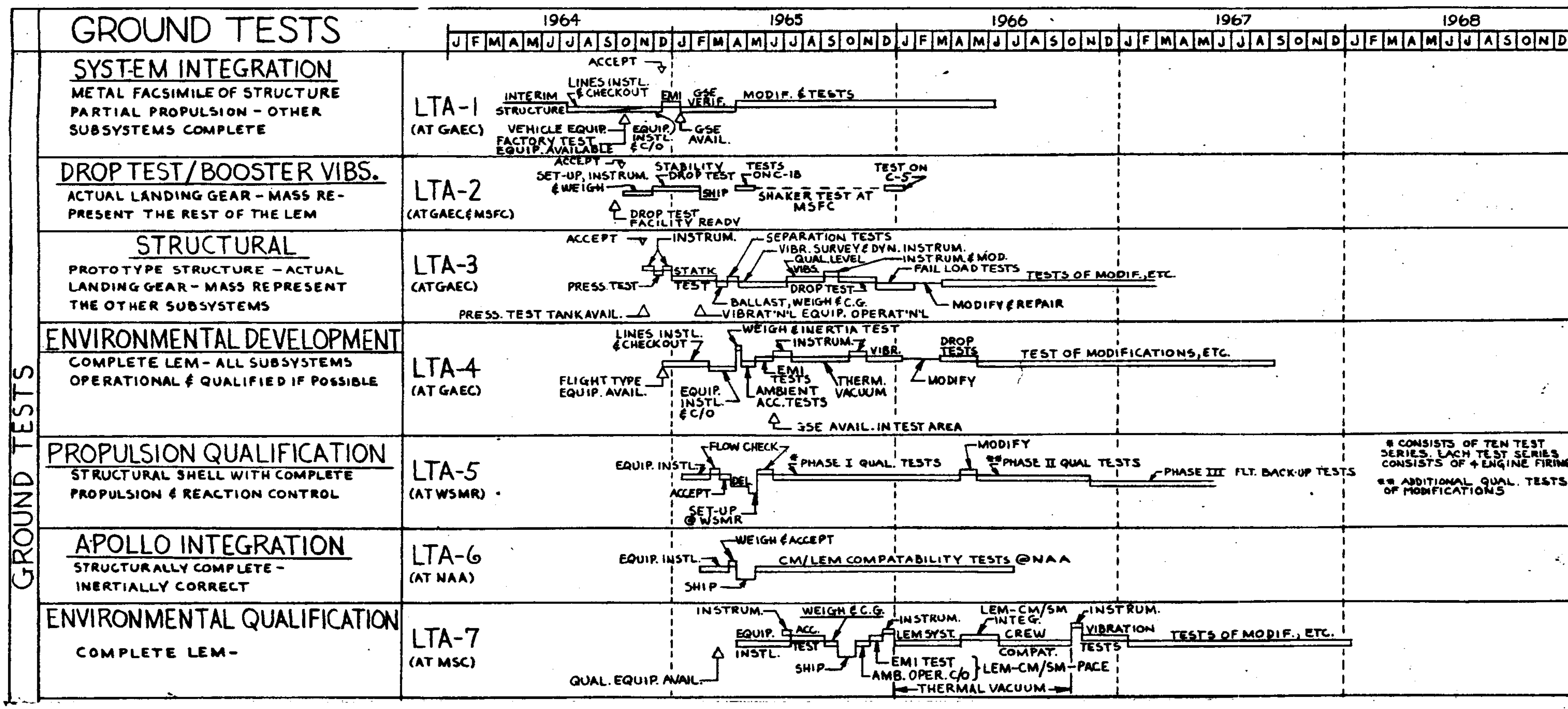

Fig. 3-2 CURRENT LEM GROUND TEST PROGRAM

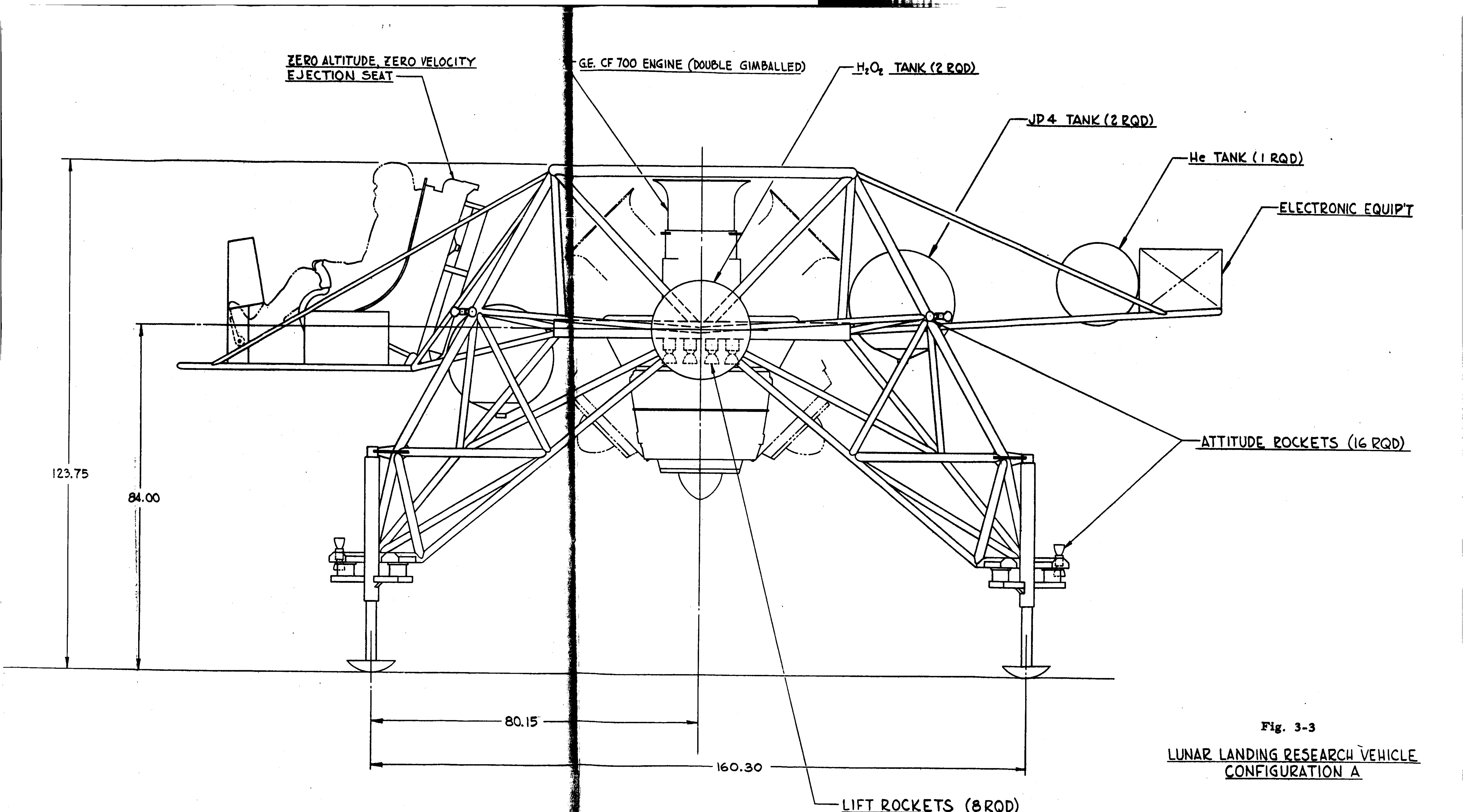

Fig. 3-3

LUNAR LANDING RESEARCH VEHICLE
CONFIGURATION A

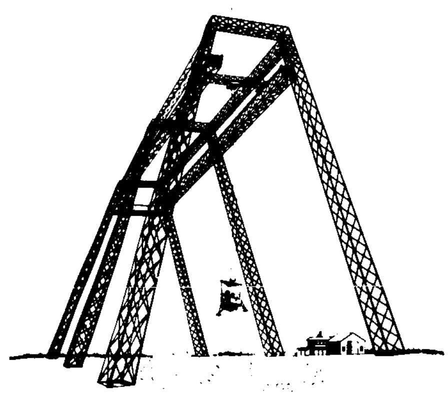

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Figure 3-4

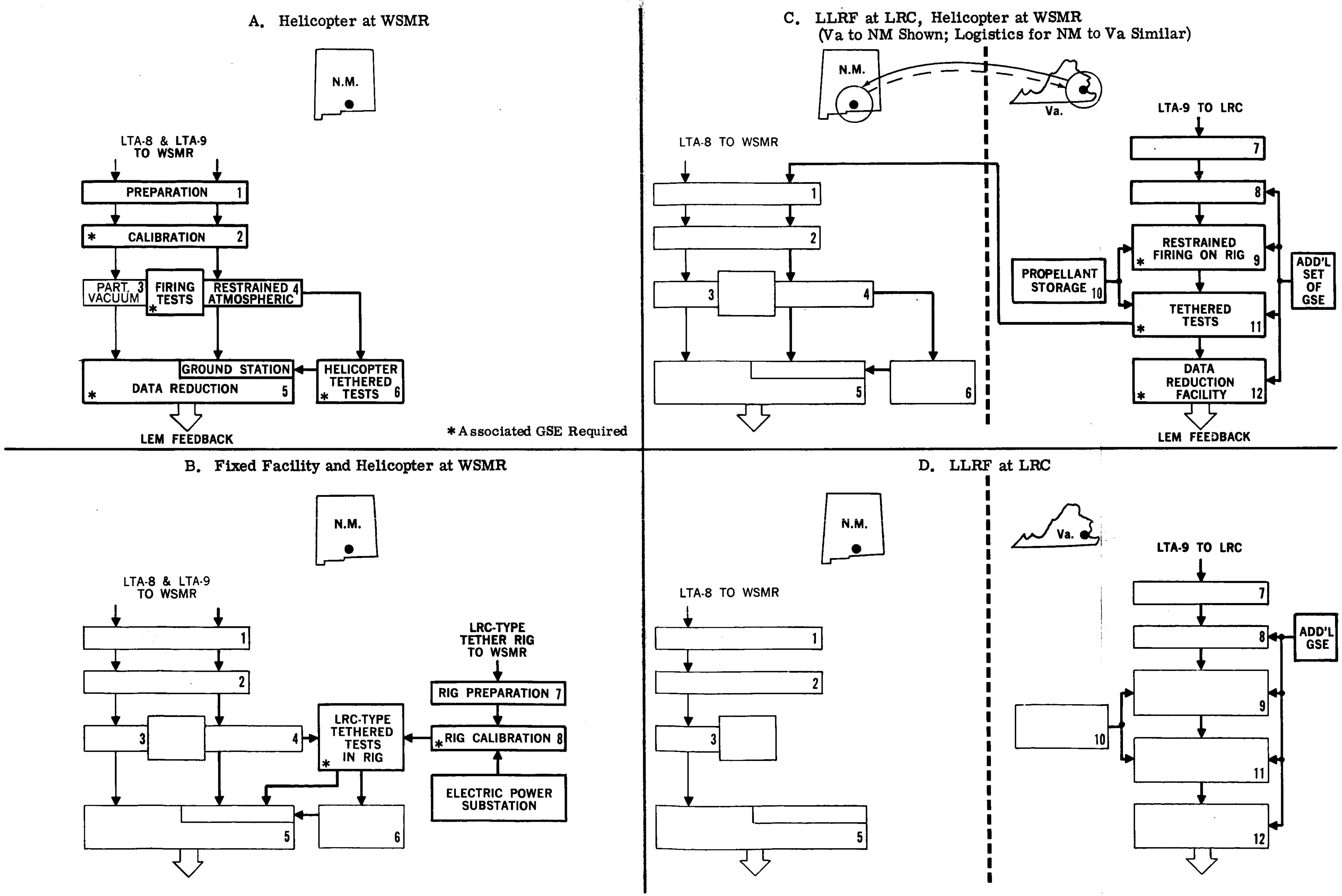
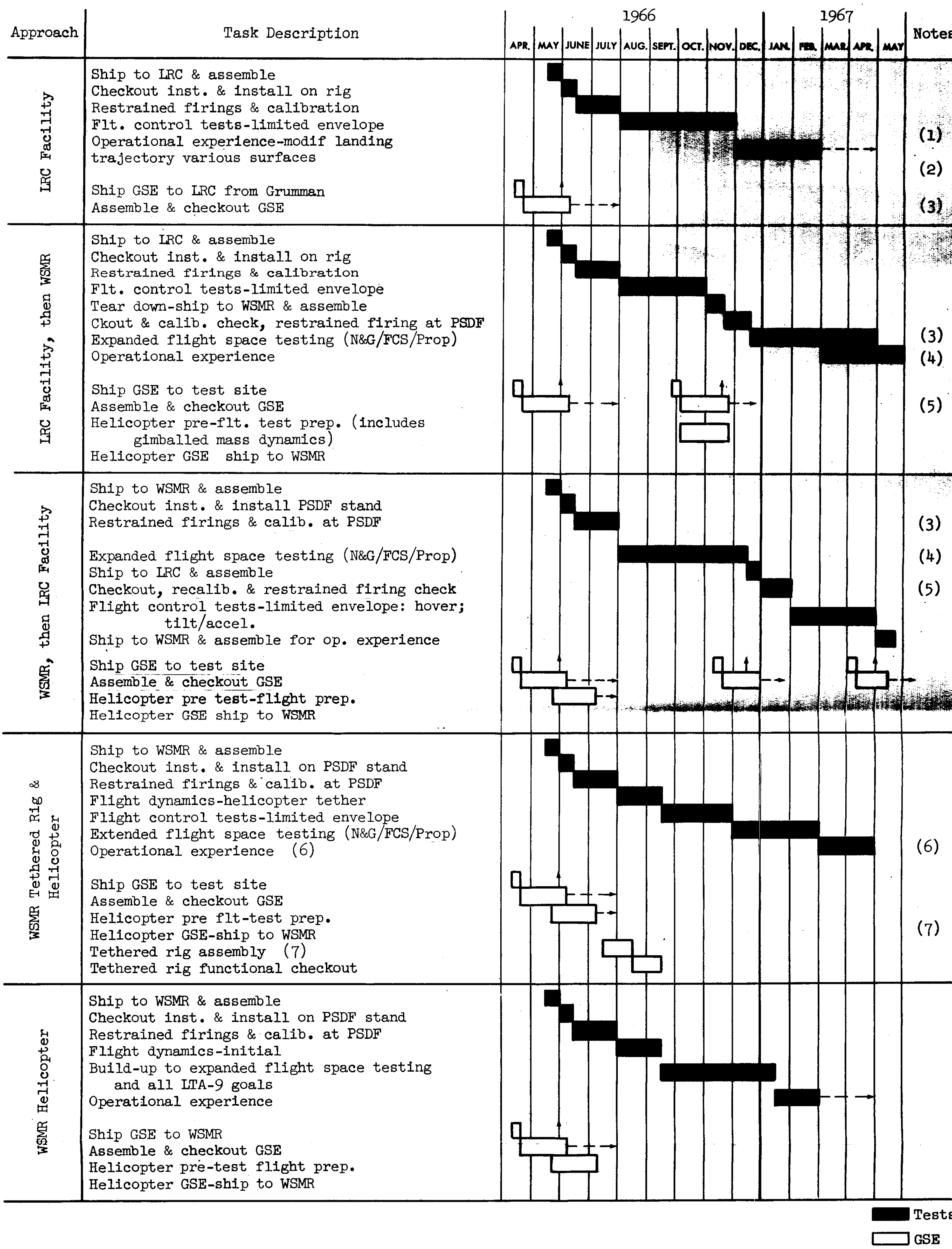


Fig. 3-5 Comparison of LTA-9 Tethered Testing Approaches with LTA-8 Restrained Firing Integrated System Tests



NOTES: (1) Near-operational experience limited by physical constraints of facility.
(2) No satisfactory method for integrated navigation and guidance subsystem tests.
(3) Two sets of GSE required. (One at LRC for LTA-9, one at WSMR for LTA-8/9.)
(4) Assume vehicles are transported between sites via aircraft.
(5) Test and operational period overlaps with shipment of LEM-9 to AMR.
(6) Combined usage of fixed and wide flight envelope tethering methods at same site.
(7) Possible utilization of LRC launching system, bridge drive dolly and hoist system.

Fig. 3-6 Comparison of Various LTA-9 Operational Procedures

4. LTA-8 RESTRAINED FIRING INTEGRATED SYSTEM TEST

4.1 TEST SUMMARY

Section 4. presents the recommended LTA-8 integrated system restrained firing test program. The discussion encompasses the test purposes, vehicle configuration, specific test conditions and the bearing of other LEM/LTA development tests upon the start or conduct of LTA-8 testing. The use of the WSMR Propulsion System Development Facility (PSDF) is required for accomplishing the test program. Emphasis is placed upon the need for altitude testing as opposed to atmospheric firing in order to perform fully worthwhile system investigations. The instrumentation approach and the utilization of the WSMR data acquisition and processing system is outlined. The scheduling aspects of the LTA-8 vehicle are described and include the inhouse Grumman vehicle acceptance phase, and the operational tests at WSMR.

4.2 TEST OBJECTIVES

The purpose of the LTA-8 restrained firing tests is to demonstrate that the integrated or interconnected LEM Subsystems can perform without degradation under the dynamic environment imposed by either the descent or ascent propulsion operating in conjunction with the reaction control rockets. An equally important goal of LTA-8 is that of serving as an integrated system test vehicle on which to investigate system problems encountered by the space flight LEM's. LTA-8 is the only vehicle that would be available, starting in early 1966, capable of combined subsystem operation with propulsion/RCS firing under simulated altitude conditions. The following table lists the primary test objectives to be accomplished by LTA-8:

LTA-8 PRIMARY TEST OBJECTIVES

1. Confirmation of the structural subsystem vibratory interaction.
   a) Throttleable descent engine plus reaction control environment.
   b) Ascent engine plus reaction control environment.

2. Confirmation of local thermal environment with operative integrated LEM subsystems.

3. Confirmation of the distribution and absorption of mechanical loads throughout the LEM system. Attention will be given to the cumulative effects of the dynamic loadings.

4.3 TEST CONSTRAINTS

Test constraints are defined as those tests which must precede the start of LTA-8 firing operations. The primary test constraint on the start of LTA-8 restrained firings is the qualification testing of the propulsion and RCS subsystems aboard LTA-5. These tests shall have progressed to the level where three to four successful firing sequences have been demonstrated. While not explicitly a test constraint, hardware availability is another factor influencing the start of LTA-8 tests (note schedule presented in figure 3.1). It is also desirable to have completed the environmental development tests aboard LTA-4, with the exception of the drop tests (since no landing gear will be installed on LTA-8. The satisfactory completion of the LTA-3 static loads tests and vibration survey is also a desirable prerequisite. The results of the LTA-3 and LTA-4 test will then provide a basis for data comparison in the areas of structural, vibratory and thermal response, as well as EMI. As indicated in the present scheduling of LTA-1 through LTA-7 (figure 3.2), test results will be attained from these articles early enough to be utilized by LTA-8.

4.4 DEFINITION OF TEST ARTICLE

LTA-8 will consist of a structurally complete LEM descent stage and ascent stage. All LEM subsystems will be installed and operative with the following modifications or exceptions:

1. Electrical Power Subsystem - Provision for LEM fuel cells will be maintained; however, it is anticipated that batteries could be utilized in place of the fuel cells.

2. Landing Gear - The landing gear will not be installed for the LTA-8 tests.

3. Crew Systems - Since the WSMR test cells are not man-rated, these tests will be unmanned, however, provisions to simulate crew metabolic loading on the system will be provided.

A complete description of the LTA-8 configuration, including a breakdown of mass properties is presented in Appendix C.

4.5 TEST CONDITIONS

The restrained firing tests of the LTA-8 vehicle will be performed using one of the three altitude chamber test stands at WSMR PSDF. The altitude test stand will permit propulsion operation over the complete LEM thrust range. The combination of partial vacuum and soft mount conditions will enable simulation of the correct vibration environment and avoid unrealistic acoustic noise effects. The ability to uncover potential integrated system problem areas is therefore, increased markedly under altitude firing conditions. Figure 4-1 illustrates the proposed test setup. The test operation will be conducted from the LEM control center building and will utilize the PSDF data acquisitioning and conditioning equipment. Figure 4-1 presents a general arrangement of the LEM PSDF and shows the proximity of the test stand complex to the preparation building. Further details on the WSMR test facilities are given in reference (6). The configuration of integrated system response to propulsion firing will encompass the following test conditions:

PRIMARY TEST CONDITIONS

Firing Duration	- Descent Engine 595 sec Minimum Ascent Engine 480 sec Minimum RCS 1000 sec Minimum
Firing Schedule	- Lunar landing mission time sequence
Subsystem Performance Investigations, Both Ascent and Descent Engines	- Various constant thrust settings plus transients, steady state thrust levels, transient response: multiple starts, shutdown, expendables depletion, abrupt descent engine throttling. Simulation of "high" and "low" as well as "nominal" test conditions.
Descent Engine	- Throttling 10:1 Gimballing $\pm$ 6°
RCS	- Minimum impulse, limit cycling, simulated maneuvers in all control modes.

During the initial LTA-5 propulsion qualification tests data will be acquired to establish nominal mixture ratios, valve settings, propellant tank pressure and temperatures for the LTA-8 vehicle. Similarly control voltages, gains, and sensitivities established during LTA-5 tests will be used initially in LTA-8. Ultimately the effects of parameter variation and simulated RCS and propulsion malfunctions on the interconnected LEM subsystems will be investigated with LTA-8. Simulated flight control and navigation and guidance inputs will be introduced into the subsystem electronic loops to check response under the environment imposed by the operating Propulsion and Reaction Control Subsystems.

4.6 LTA-8 PROGRAM SCHEDULE AND DESCRIPTION

The integrated system-restrained firing test vehicle LTA-8 will be shipped to WSMR in December of 1965, after completing vehicle acceptance testing at Bethpage. LTA-8 acceptance tests will include electrical and electromagnetic interference checks, a ground vibration survey, and confirmation of vehicle weight and balance. Subsystem development and qualification for LTA-8 should not be critical, since the onboard subsystems are virtually identical with the equipment installed in LTA-7 and the space flight LEM's. The key scheduling factor will be availability of LEM equipment for vehicle installation. The earliest date for equipment availability is March 1965.

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Following the arrival of LTA-8 at the test site, the instrumentation calibration and vehicle test-stand checkout will be performed. Initial firings will be short duration runs for:

1. Gross determination of the environmental effects of propulsion and reaction control, and engine calibrations.

2. Determination of critical interfaces between connected subsystems.

3. Demonstration of repeatability of test conditions.

4. Confirmation of ground support techniques.

The full duration firing tests will commence by February of 1966. The testing schedule for the LTA-8 firing tests are shown in figure 4-3. The test firing sequence will be nominally the same for each run. The emphasis on each firing will be upon different subsystem combinations and control modes. During the first series of full duration firings primary attention will be given to investigation of the interconnected flight control guidance and navigation subsystems. Each control mode: direct, attitude hold, attitude command, and automatic, will be evaluated. In addition, the consequences of mode shifting while firing will also be evaluated. Subsequent firings will concentrate upon the ECS and EPS subsystems performance. Eventually, LEM-8 will serve as a testbed for detailed investigation of space LEM problems and as an important means of confirming solution to these problems prior to a scheduled space flight.

It an anticipated that all onboard subsystems will be monitored during any firing. However, the detailed test sequences and instrumentation will be tailored for the particular subsystem groupings under consideration on any one firing. Onboard motion picture camera coverage of displays in conjunction with appropriate vibration transducers would be used to check readability under engine firing conditions.

Pre-test and post-test subsystem checkout will be performed using LEM Special Test Units (LSTU's). The LSTU noted in Section 7 provides input stimuli and ascertains the status and functional capability of the onboard operational subsystem equipment.

4.7 INSTRUMENTATION AND DATA ACQUISITION

The LTA-8 instrumentation approach is to utilize the LEM operational instrumentation (PCM) link with hard-line transmission from the test stand to the WSMR Data Acquisition System. Additional measurements that are not handled by the LEM PCM will be recorded via a hard-lined FM/FM/PAM (LEM R & D) instrumentation link. The use of LEM operational and R & D telemetry not only helps fulfill the integrated system test objectives, it also expedites pre-test instrumentation checkout. The number of individual instrumentation lines running from the vehicle through the test chamber is minimized by the hard-lined telemetry approach and is therefore, advantageous from the altitude facility operational standpoint.

The 51.12 kilobit PCM link will be complemented with two R & D packages utilizing IRIG subcarrier bands 2 through 16 and E. Commutation rates of 90/1 and 90/10 are planned for subcarrier bands 13 and E, respectively. However, other methods for sampling high-frequence vibration (to 2000 cps) data are under study. Should the number of high-frequency vibration duty channels become greater than the combined capacity of the FM/FM/PAM packages, direct measurement can be hard-lined to the control room.

The WSMR Data Acquisition and Processing System is located in four general areas: test chambers, signal conditioning rooms, cable tunnels, and the control center (see figure 4-4). The system consists of five major subsystems:

1. Signal Conditioning
2. Digital Recording
3. Analog Recording
4. Test Monitoring Display
5. Interface and Analog Data Reduction

Preliminary schematic diagrams of the digital and analog subsystems are shown in figures 4-5 and 4-6, respectively.

The above mentioned equipment provides a display of data for rapid, efficient evaluation of test parameters to meet the varying requirements and numbers of dynamic, quasi-static and static measurements. The distribution patch panels provide a reasonable amount of flexibility for handling the unpredictable situations often arising in an operational test program such as LTA-8.

A detailed instrumentation list for LTA-8 is beyond the scope of the preliminary design effort, but will be implemented during the initial stages of detail design.

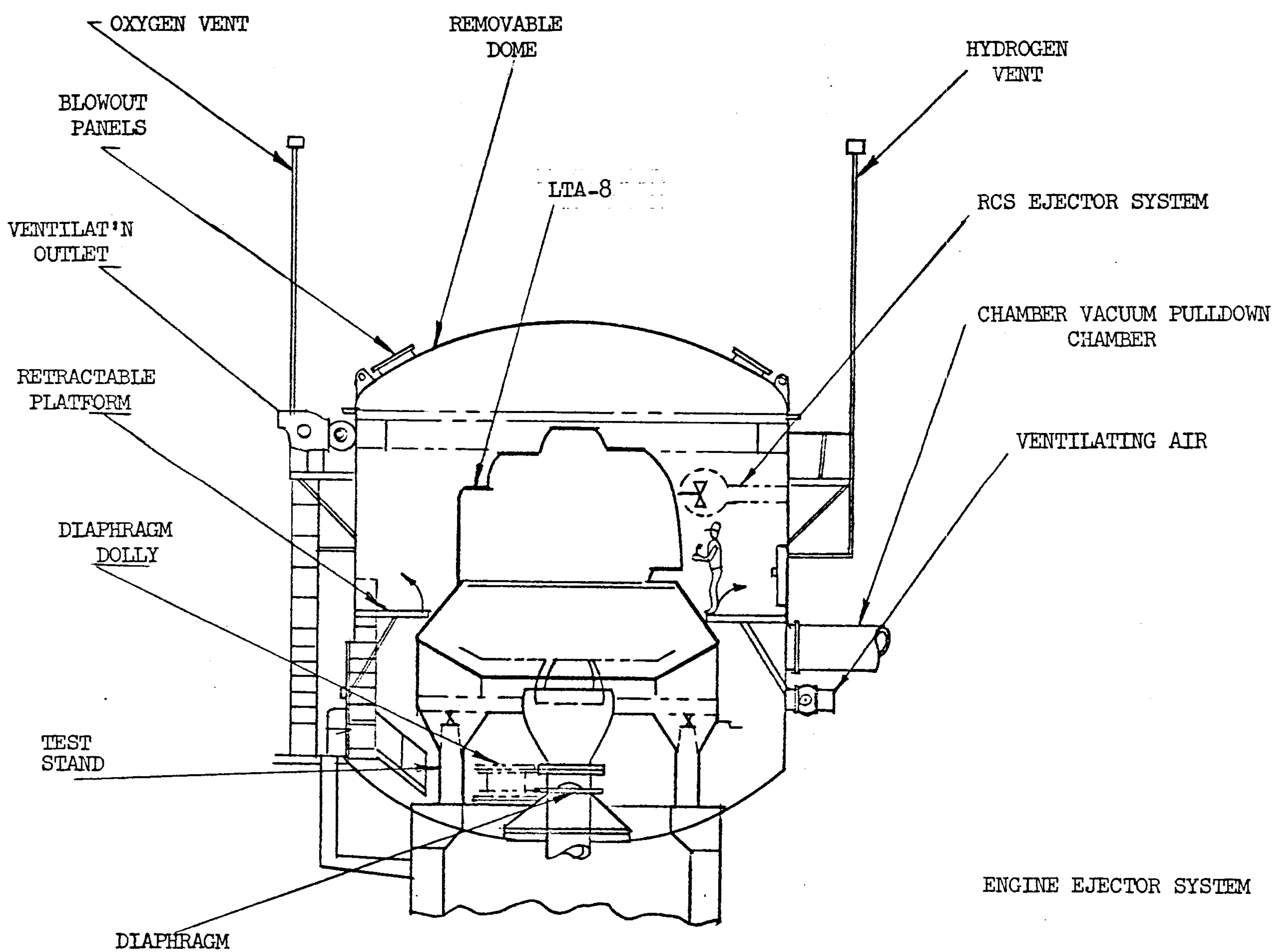


FIG. 4-1

LTA-8 INSTALLATION IN PROPULSION SYSTEM TEST STAND WSMR

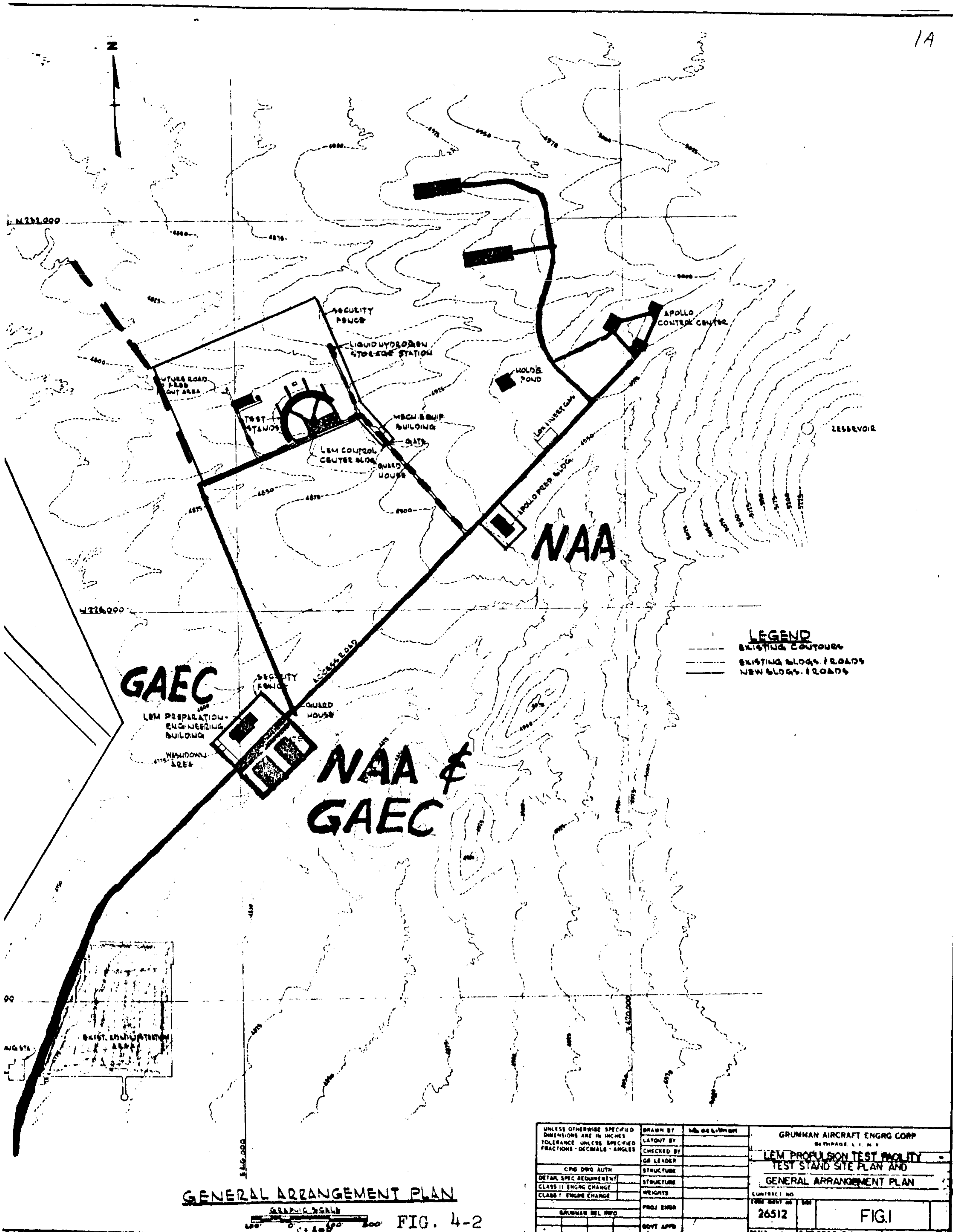

1A
N
N 232,000
N 228,000
SECURITY FENCE
LIQUID HYDROGEN STORAGE STATION
TEST STANDS
MECH EQUIP BUILDING
GATE
LEM CONTROL CENTER BLDG
GUARD HOUSE
HOLD'G POND
APOLLO CONTROL CENTER
APOLLO PREP BLDG
NAA
RESERVOIR
LEGEND
EXISTING CONTOURS
EXISTING BLDGS. & ROADS
NEW BLDGS. & ROADS
ACCESS ROAD
GAEC
SECURITY FENCE
GUARD HOUSE
LEM PREPARATION-ENGINEERING BUILDING
WASHDOWN AREA
NAA & GAEC
EXIST. ADMINISTRATION AREA
GENERAL ARRANGEMENT PLAN
GRAPHIC SCALE
GRUMMAN AIRCRAFT ENGRG CORP
LEM PROPULSION TEST FACILITY
TEST STAND SITE PLAN AND
GENERAL ARRANGEMENT PLAN
26512
FIG.1

FIG. 4-2

Preparation Building

1. Receiving Inspection:
   D/S (4)*
   A/S (7)

2. Install in C/O stand, equipment installation and calibration of transducers. Perform pressure & leak check:
   D/S (12)
   A/S (20)

3. Mate stages-interface checks. Electrical continuity checks & functional tests (7)

Test Stands

4. Install A/S on tests stand "A" connect facility & GSE umbilicals, test instrumentation & control systems, propellent tanking & pressure tests (12)

5. Install D/S on test stand "B" (C/O & test similar to A/S) (5)

6. Prefiring inspection of A/S on test stand "A". Acceptance & calibration firing test of A/S. Post firing inspection (9)

7. Mate A/S to D/S on stand "B", check structural interface, connect umbilicals to A/S. Functional checks of subsystems GSE, instrumentation and control checks. Perform acceptance & calibration firing test of D/S (12)

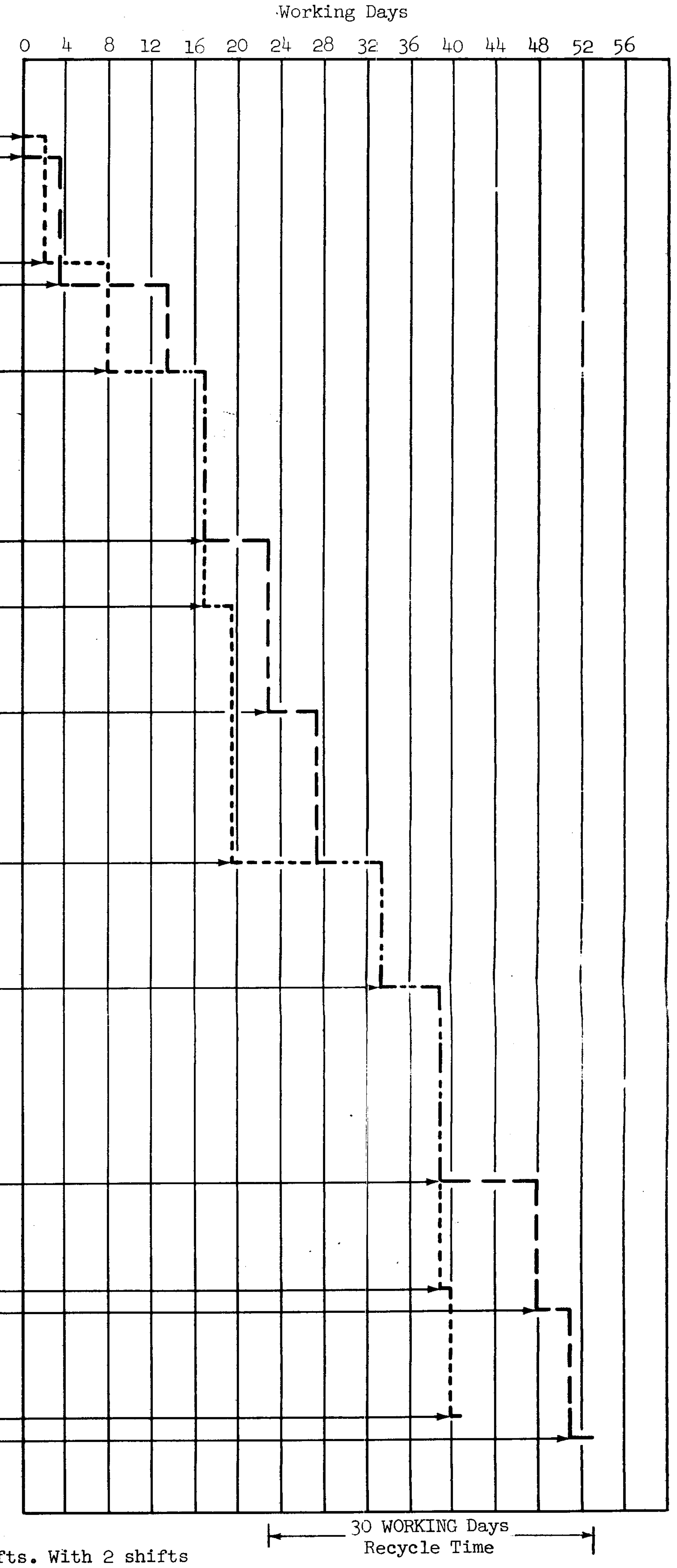
8. Propellant tanking on test stand "B" Subsystems readiness test. Perform full-firing sequence (D/E & RCS). Post-test inspection, quick-look data evaluation (11)

9. Move A/S back to test stand "A" Reconnect umbilicals, instr. checks Functional tests of subsystems Propellant Tanking Subsystems readiness test Perform full-firing sequence (A/E & RCS) Post-test inspection, quick-look data evaluation (18)

10. Remove used engine, clean up & inspect subsystems. Install new engines and other components as necessary:
    D/S (on test stand "B") (2)
    A/S (on test stand "A") (5)

11. Perform functional tests with new engines, instrumentation calibration pressure & leak checks:
    D/S (on test stand "B") (3)
    A/S (on test stand "A") (5)

12. Repeat of steps 6 through 11.



*( ) Numbers in parentheses indicate no. of work shifts. With 2 shifts per working day, each number is therefore twice the number of working days

LTA-8 RESTRAINED FIRING PLAN

Full duration firing tests to investigate interconnected subsystems. Test emphasis shifts to different subsystem combinations and control modes for each run sequence.

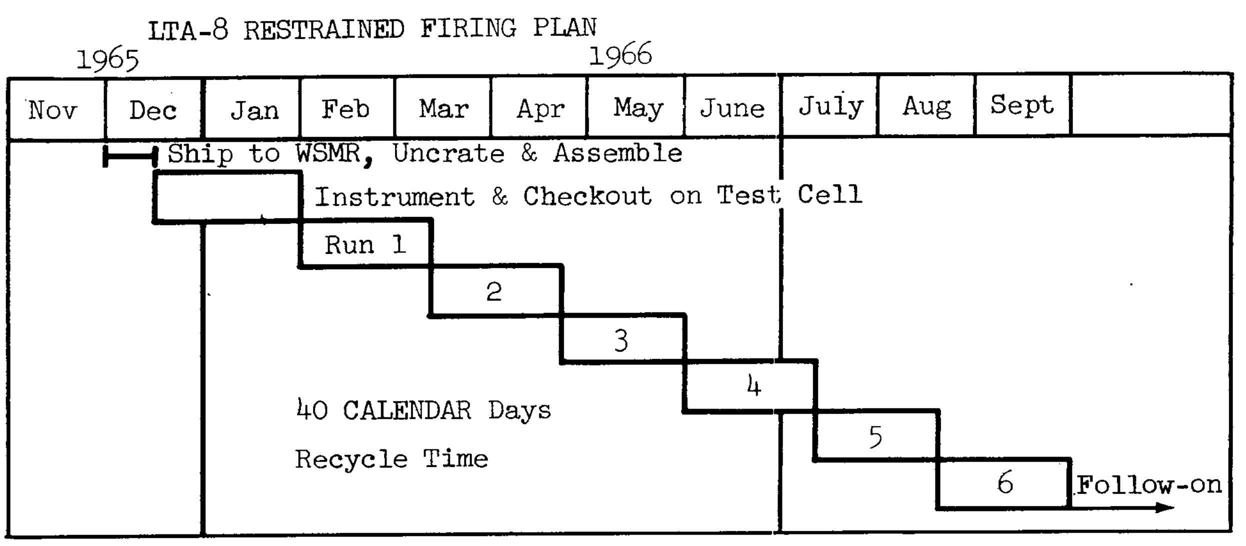


Fig. 4-3 LTA-8 Testing Schedule

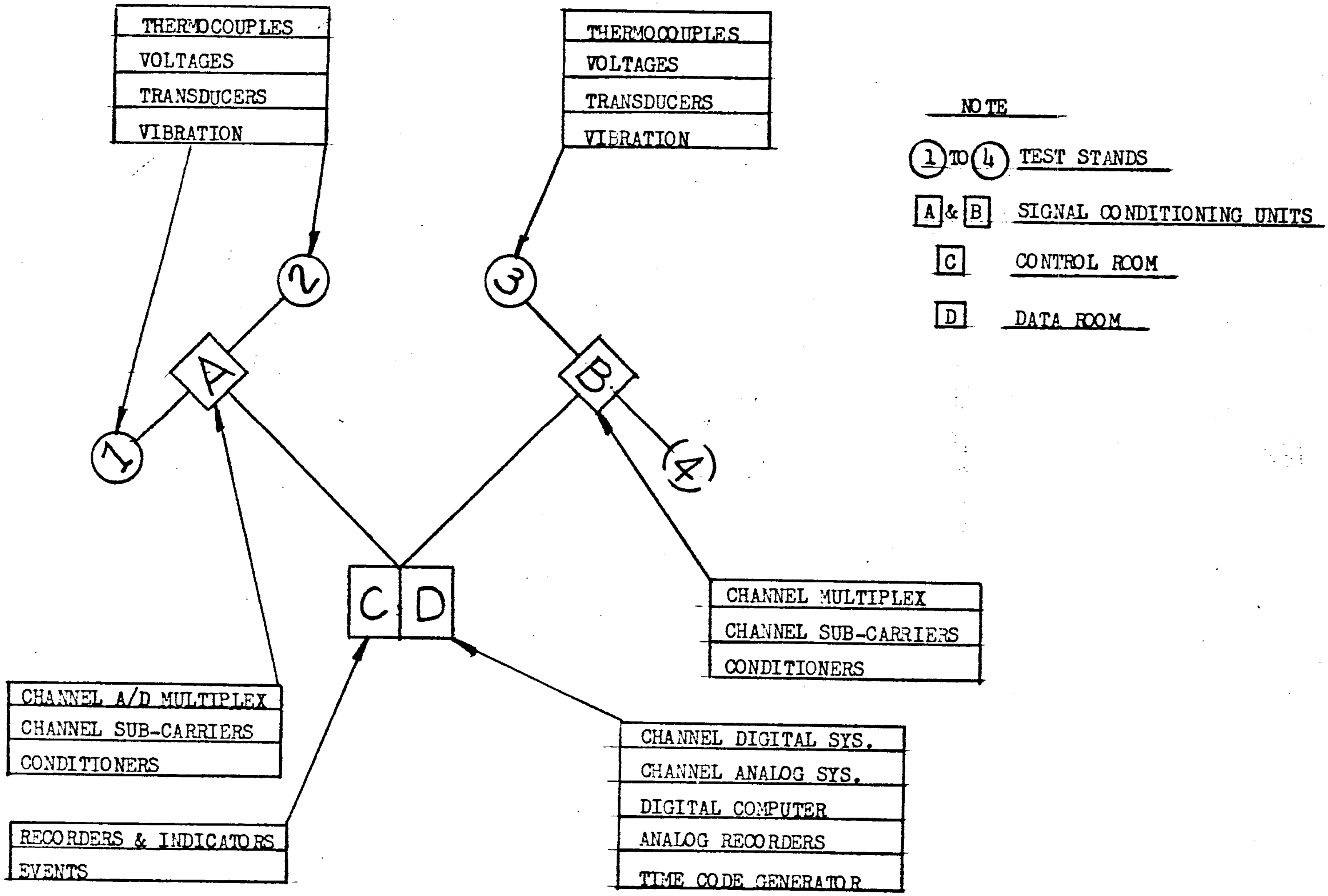


FIG. 4-4

W.S.M.R. DATA ACQUISITION AND PROCESSING SYSTEM-PHYSICAL CONCEPT

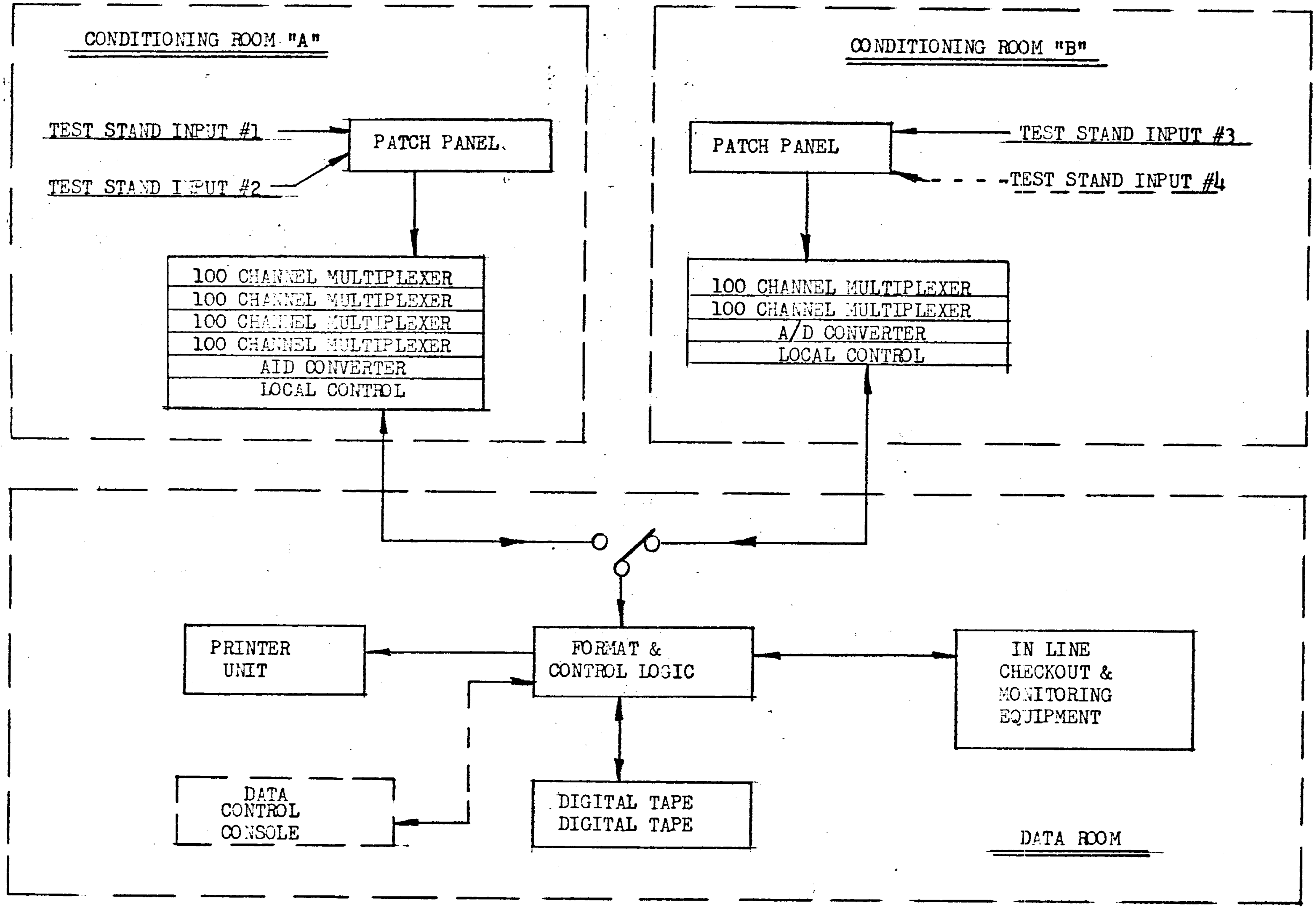
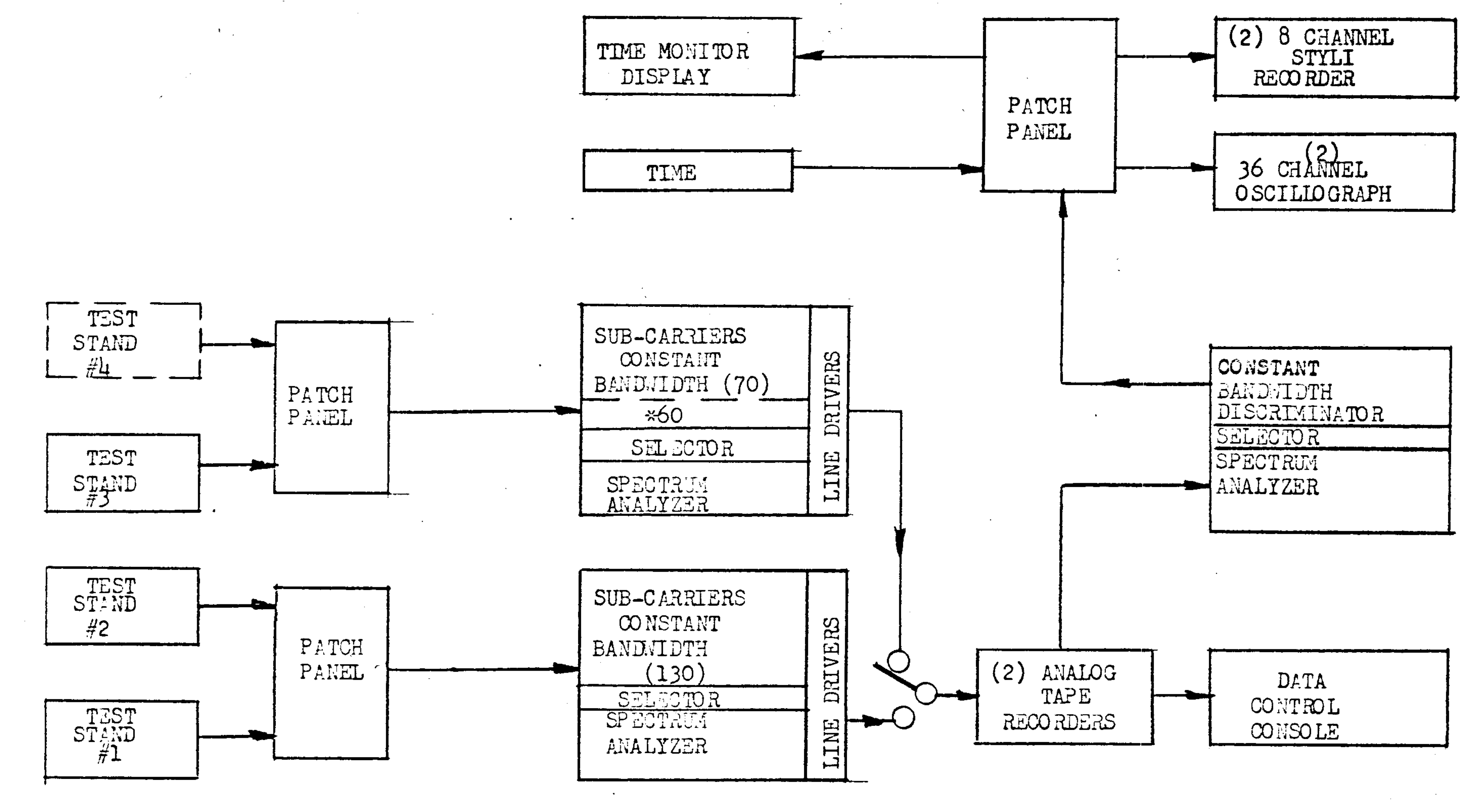


FIG. 4-5

W.S.M.R. DIGITAL SUBSYSTEM



NOTE: * PREWIRED RACK EXPANSION

FIG. 4-6

WSMR ANALOG SUB-SYSTEM

5. LTA-9 DYNAMIC TEST OF INTEGRATED LEM SYSTEMS

5.1 TEST SUMMARY

Section 5 presents the test plan by which an all-rocket powered LEM employing the minimum modifications required for atmospheric flight operations can perform dynamic integrated system confirmation. Flight capabilities are provided by tethering the vehicle, designated LTA-9, to a movable support. Major emphasis is given to comparing the LRC-type ground tether facility with helicopter-tether methods of conducting the atmospheric flight operations.

The test objectives described are designed to provide LEM system operational experience and uncover subsystem weakness, fatigue, maintenance and operational compatibility problems which will enable upgrading and refinement of the manned LEM spacecraft. The LTA-9 vehicle is described and compared with a space flight LEM. Preliminary program scheduling and a discussion of the test constraints and support equipment are also presented.

5.2 LEM SYSTEM BACKGROUND INFORMATION

Four LEM subsystems of primary importance in the hover and landing operations of LTA-9 are the:

(1) Descent Propulsion Subsystem
(2) Reaction Control Subsystem
(3) Stabilization and Control Subsystem
(4) Navigation and Guidance Subsystem

A brief review of the interrelations of these subsystems during LEM landing maneuvers prior to discussion of the LTA-9 test program is given below.

Three possible modes of LEM attitude control can be used during the landing phase in addition to fully automatic landing. The manual LEM control modes are:

(a) Attitude Hold Mode. The pilot commands LEM pitch, roll and yaw attitude rates proportional to controller displacement. When the controller is returned to neutral, the vehicle will hold the last commanded attitude. This mode will be used during hover and descent for movement about the LEM roll axis and for back-up of the Attitude Command Mode.

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(b) Attitude Command Mode. The pilot commands LEM pitch and yaw attitude proportional to controller displacement. When the controller is returned to the neutral position, the vehicle returns to the vertical. This mode does not control motion about the roll (vertical) axis.

(c) Emergency Attitude Mode. The pilot commands vehicle rotational acceleration on an individual axis basis through open loop, on-off control of the RCS. This mode represents the most degraded control system condition and provides backup control in the event of failure of the alternate modes.

The RCS and S&C, a major loop of which is the Descent Engine Control Assembly (DECA), form the Flight Control System. However, sections of the N&G subsystem are closely tied to the successful operation of the flight controls. The Primary Guidance Section (PGS) commands and control signals for the semi-automatic control modes (a and b above) are provided by the Inertial Measuring Unit (IMU) and Apollo Guidance Computer (AGC) through the Guidance Coupler Assembly (GCA) in the S&C subsystem. The Primary Guidance Section in the N&G subsystem also provides signals for motivating the DECA which provides automatic trim control. In the fully automatic landing mode, the PGS also supplies signals for automatic descent engine ignition, throttling and shutdown. Further interrelations between S&C and N&G electronics exist, since the landing radar provides updating information to the inertial reference equipment in both the Primary Guidance which is located in the N&G subsystem and the Backup Guidance in the S&C subsystem. The system integration diagram shown in figure B-1 schematically indicates the functional interdependence of the key LEM subsystems during flight operations.

5.3 TEST OBJECTIVES

The purpose of the LTA-9 dynamic test program is to gain near-operational system operation and flight experience within the atmosphere. LTA-9 provides the only opportunity in the LEM program to perform repeated terminal descent tests prior to manned lunar landings. The test results will confirm the capability of the LEM and its interconnected subsystems to perform the terminal descent phase of the LEM mission. This experience will also provide the opportunity to upgrade and refine actual LEM equipment and techniques in a powered flight environment. These tests will also provide additional reliability data on LEM components and are a means of increasing confidence in:

(1) Satisfactory integrated system operation, and
(2) Man-managed LEM control and dynamics for the lunar landing.

The primary test objectives to be accomplished with LTA-9 are given in the following section.

5.3.1 LTA-9 Primary Test Objectives

1. Evaluation of Combined Subsystem Performance. Particular emphasis will be given to the Flight Control System which is composed of the Reaction Control Subsystem, the Stabilization and Control Subsystem, and utilizes sections of the Navigation and Guidance Subsystem (see figure B-1). Vehicle response under descent engine dynamics induced by engine starts, throttling, maximum (atmospheric) thrust, engine gimballing and pilot/engine transients will be evaluated. These evaluations will be performed in each LEM control mode: Attitude Hold, Attitude Command, Direct (on-off Emergency Mode), and Automatic. Flight control capability will be checked throughout the lunar landing terminal descent flight envelope and will include: hover, attitude holding and translation, controlled descent, touchdown, and to practical limits, abort. While the velocity profile of the Powered Descent Phase of the mission cannot be matched in atmospheric LEM flight operations, the applicable flight control functions and sequences will be evaluated. Accuracies will be compared with predicted or design values to confirm performance level.

2. Evaluation of Subsystem Functions. Functional checkouts of the interconnected subsystems to confirm or upgrade gain and balance parameters in near-operational flight conditions will be conducted. In the flight control area, the following sequences or operations will be investigated with regard to the effects of off-nominal parameter settings.

   (a) Limit cycle and deadband zone.
   (b) Closed loop stability, damping, and coupling.
   (c) Gain and control sensitivity.
   (d) Control threshold, minimum impulse.
   (e) Vehicle motion cross-coupling.
   (f) Throttle sensitivity and c.g. shift compensation.
   (g) Mode switching.

   In the Navigation and Guidance area, the prime objectives are to ascertain N&G compatibility with the flight control system with and without descent engine firing and confirm satisfactory man usage of the integrated subsystem. The LTA-9 functional evaluations include:

(a) Radar equipment (rendezvous radar and transponder as well as the landing radar), signal output and tracking under low velocities and dynamic flight conditions over a range of surface reflectivities.

(b) Inertial and inertial/radar operations including updating capability over a range of inserted initial errors.

(c) Optical landing assist devices in near-operational vibratory environment (within the constraints of atmospheric refraction and lighting).

(d) Verification of sequential and intrasubsystem functions between the Apollo Guidance Computer, Inertial Measuring Unit (modified for atmospheric operations), Power Servo Amplifier, Coupling Display Unit, Optical Equipment Displays and Controls, and Radars in near-operational terminal descent.

3. Evaluation of Potential Subsystem Malfunctions and Degradations. The end-to-end connected subsystems will be evaluated to determine the effects of supply voltage variation, mode switching transients, structural/subsystem element coupling. Excessive vibration, local equipment over-heating and inadvertent overloading are potential failure modes in vehicle dynamic testing, and these situations will be carefully monitored during the atmospheric flight tests. The tethered flight investigations will include:

(a) Transient electrical effects of reaction control pulsing.
(b) Reaction control quad malfunctions.
(c) Stabilization and Control electronic logic malfunctions.
(d) Electrical power supply failure
(e) Electrical hardware degradations and failures
(f) Controller malfunctions
(g) Transient effects resulting from mode switching (e.g. switching from primary to back-up guidance system, switching between semi-automatic, automatic and direct modes of flight control).

4. Near-Operational Experience with Man-in-Loop. LTA-9 will permit crew evaluation and experience with the actual combined LEM subsystems in as near lunar landing conditions as possible. This operational experience in a minimum

modification, all-rocket LEM will complement the flight crew training defined in reference (7) with first-hand experience using actual LEM equipment.

The man-vehicle flight test objectives are:

(a) Evaluation of and experience with flight controls with LEM descent engine firing.

(b) Confirmation of the crew's ability to effectively interpret and utilize the LEM displays and controls during precision terminal descents; particularly flight control, navigation and guidance and propulsion subsystem displays and arrangements.

(c) Evaluation of the automatic versus semi-automatic landing modes. Experience with conditions under which crew over-ride of automatic functions is necessitated.

(d) Maneuvering experience with LEM vehicle, including attitude control, establishment and arrestment of descent rates: translational flight with tilted thrust vector and translational jets; three-dimensional flight dynamics, overshoots and dynamic response.

(e) Crew considerations and subsystem management during and following ground contact, including thrust termination, landing under various surface and grade combinations.

(f) Error sensing and corrections to flight trajectory, precision timing and practice of alternate flight path transfers.

(g) Evaluation of man-LEM techniques and landing aids such as radar beacon, visual beacon and penetrometer devices.

(h) Experience with the use of LEM radar and radar displays during landing.

5.4 TEST CONSTRAINTS

The primary test constraints on the initiation of dynamic flight tests of the integrated LEM system using LTA-9 are:

(1) The qualification of LEM subsystems for manned tethered atmospheric operations aboard LTA-9.

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(2) The availability of tethering systems to accomplish the dynamic test objectives.

The atmospheric flight environment necessitates modifications to the basic LEM vehicle (see Section 5.5 and Appendices B and C) that will require additional qualification beyond that planned for the basic LEM. The pre-tethered flight qualification and functional checkout of LTA-9 equipment includes:

(1) RCS and descent propulsion subsystems qualified for manned atmospheric operations.

(2) Structural qualification of the complete vehicle and vehicle gimbal device. This includes static loads, vibration, pressure check and landing impact.

(3) Electrical load and EMI check of the integrated subsystems aboard the vehicle.

(4) Verification of the modified LEM environmental control subsystem's ability to maintain proper thermal control of the integrated subsystems and provide for crew comfort and safety.

(5) Pilot familiarization with LTA-9/LEM flight characteristics by virtue of prior experience with the LEM ground based simulators and the NASA lunar landing research vehicles at LRC and FRC.

In order to assure safe tethered flight capability, the LTA-9 development program starts with subsystem development, builds up to vehicle proof tests at Grumman and then to restrained, environmental check firings at the test site, prior to the manned tethered operation.

A satisfactory tethering system must have the capability of:

(1) Operating with a LEM descent engine nominally thrust-rated between 1050 and 7000 lbs. in the atmosphere.

(2) Permitting investigation of vehicle trim and moment with minimum side effects.

(3) Providing flight space consistent with the test objectives (Note: The radar test objectives require the largest flight envelope).

(4) Operating at velocities up to LEM aerodynamic limit speeds for practical test run durations.

(5) Demonstrated provisions for vehicle, crew and ground personnel safety.

Prior to the start of manned tethered operations, the selected tethering system shall have demonstrated its ability, to safely operate with an LTA-9 type payload, and to permit the accomplishment of LTA-9 test objectives.

5.5 DEFINITION OF TEST ARTICLE

LTA-9 will be a minimum modified all-rocket LEM. The vehicle will consist of a structurally complete descent stage and ascent stage with the LEM ascent tankage and plumbing plus a dummy ascent engine. The descent engine, reaction controls, and environmental control subsystems will be suitabl modified to function in an atmospheric environment. The electrical power distribution section will be complete. However, it is recommended that a battery power supply will be substituted for the LEM fuel cells. The S-band communications equipment will not be exercised during these tests due to incompatibility with available WSMR frequencies and could be replaced by a simulated electrical load if required.

The major structural modifications will include heat protection in the descent engine well and gimbal interface structure which will pick up existing descent stage hard points. Since the tethered system will support 5/6 of the vehicle's weight, a LEM landing gear will be used. The crushable honeycomb shock absorbing cartridges will be replaced after each landing.

Flight control electronics and navigation and guidance subsystem modifications will include accelerometer scaling changes and computer programming to compensate for the earth gravitational environment. The gimballed rendezvous radar and elements of the landing radar (i.e., antenna and mechanisms) may require modification because of the extensive earth landing operations.

A complete description of the LTA-9 test configuration is presented in Appendix C. However, table 5.1 summarizes the major subsystem modifications for an atmospheric tether flight LEM.

5.6 TEST CONSIDERATIONS

5.6.1 Free Flight LTA-9

Accomplishment of the LTA-9 dynamic test objectives requires either vehicle modification or devices for extending atmospheric flight capabilities. Reference (8) presented a "jet levitation" approach for developing a precise engineering free-flight simulator and trainer. This approach was too complex to provide reasonable assurance of availability in the allotted development time. The present study has indicated that an off-loaded free flight LTA-9 configuration is unsatisfactory

Table 5.1

Vehicle Modifications for Tethered LTA-9 Flight	
Subsystem	Modification
Structure	1. Install gimbal and interface structure. 2. Add descent engine heat shielding provisions.
S&C	1. Modify electrical gains and balance.
N&G	1. Change AGC program (memory core modifications) 2. Scale modifications to inertial elements 3. Possible mechanical modification to radar gimbals and antennas (aerodynamic loading).
Crew Systems	1. Omit food, drinking water and lunar stay expendables.
ECS	1. Freon replaces water in water boil-off loop 2. Regulators readjusted 3. Crew compartment cooling fans resized.
Landing Gear	1. Replace crushable honeycomb shock absorber cartridges after landing.
Instrumentation	None
EPS	1. Replace fuel cells with battery power supply.
Propulsion	1. Inert ascent propellant and dummy engine. 2. Modify descent engine nozzle expansion ratio and throttling ratio with resultant reduction in Isp and thrust.
RCS	1. Modify nozzle expansion ratio, reduction in Isp and thrust.
Communications	1. Omit S-band equipment and replace with equivalent electrical load. (No S-band operational capability at LTA-9 test sites.)

for several major reasons:

(1) The degree of modification required to achieve free flight compromises the attainment of test objectives.

(2) Free flight time is severely limited, even with off-loading of unexercised equipment.

(3) The flight envelope, even with an assisted takeoff, is limited to altitudes below 500 feet.

(4) The flight velocity/attitude relationship is non-LEM (i.e., non-lunar).

(5) Maximum atmospheric thrust, on the order of 7000 lbs., is requred for most of the trajectory.

(6) The atmospheric ground effect is negative and causes unstable pitching moments.

(7) The single engine, weight limited, short flight duration vehicle unduly compromises crew and vehicle safety.

Appendix H discusses the reasons for discarding the free-flight vehicle in greater detail.

5.6.2 Tethered LTA-9

In reviewing both the fixed facility and helicopter tether methods for extending atmospheric flight capabilities to LTA-9, each method satisfies or is best suited for certain LTA-9 test objectives or operational standards.

In the case of fixed LRC-type tethered facilities, the potential exists for investigating vehicle trim and moment characteristics, and lunar tilt/acceleration response within a limited translational envelope. From the standpoint of flight safety, the fixed facility provides more positive control for automatic landings, near-ground hover and touchdown flight control investigations. Helicopter tethering using an adaptation of state-of-the-art helicopter-tethering technology (see Appendix K for description of the different helicopter methods studied) would expand the flight-space and flight time available to investigate LEM flight dynamics. However, some sacrifice in maneuvering precision in near ground flight tests may result from helicopter downwash effects. For acquiring operational experience with primary guidance and navigation equipment, landing radar and radar-inertial sequences the helicopter tether would provide a far more suitable capability. In addition to the expanded flight envelope, use of the helicopter also avoids the effects introduced by the steel gantry if radar tests are conducted on LRC-type tethered facilities.

Earlier, in section 3, a comparison of different operational combinations of fixed and helicopter tether methods as shown. (See the comparative schedules in figure 3.1) In section 7, a preliminary list of the GSE and facilities to support a tethered operation for the different test methods and test sites is presented.

The cable dynamics, vehicle-cable interaction problem areas and their effect on LTA-9 dynamics are to a large extent common to both the ground and helicopter tether approaches. Appendices D through F treat and evaluate these problems analytically. Appendix G treats the operating problems associated with the tether test facility locations.

5.6.3 Flight Operational Ground Rules

Regardless of the method(s) of tethering, the tethered test operational approach is basically similar. A progressive build-up will start with short duration restrained firings to first calibrate and then demonstrate satisfactory atmospheric propulsion and RCS subsystem operation and integrated system capability to function under a man-controlled propulsion environment. The initial test flights will demonstrate the tether concept and vehicle gimbal, checkout ground equipment and personnel and develop coordination between the LTA-9 crew and the tether device crew (e.g., ground facility crew or helicopter crew). These flights will not require descent engine firing; upon successful completion of the tether concept flights, rocket powered tests will commence. The non-firing trajectories would be prerequisite crew checkouts. Later, as operational experience develops, non-descent engine flight would perform specialized investigations including radar/flight control tracking and testing and visibility evaluation, or flights to gather supporting data.

For flight planning purposes, descent engine firing time per flight is assumed to be 120 seconds. Nominal test flight durations for* non-descent engine tethered flight (such as flights for investigation of landing radar updating inertial reference data in terminal descent tracking maneuver) is assumed to be five minutes. It is anticipated that an average of five flights per month will be flown utilizing descent engine rocket power. It is estimated that seven unpowered flights per month could be performed in conjunction with the powered flights. The priority of non-descent engine powered flights is secondary to descent engine powered flight tests.

Since the tethered operations would not require extensive usage of full atmospheric thrust (the tether is supporting 5/6 of the vehicle's weight), the thrust chamber operating pressure would be well below maximum rated. Cumulative

* Primarily applicable to helicopter tether.

descent engine life under these conditions is estimated at 3600 seconds and thrust chamber life at 1200 seconds. Following each flight, the test data and hardware will be inspected to assure quality and flight safety. Particular emphasis is to be given the propulsion and RCS components.

As a precautionary measure, the descent engine will be removed after the initial series of atmospheric runs and will be disassembled for thorough component inspection and analysis. Total test time on the engine at this inspection will be 720 seconds, the equivalent of six nominal LTA-9 test runs.

A preliminary descent engine utilization schedule is included in figure 5.1. The schedule also indicates the sequence for investigating the primary test objectives and the manner in which operational flight experience is progressively built up.

5.7 LTA-9 PROGRAM SCHEDULE AND DESCRIPTION

The integrated LEM system dynamic test vehicle, LTA-9 will be delivered to the test site in May of 1966 (see figure 3.1). The build-up and accomplishment of the primary test objectives are programmed for completion by the April of 1967, coinciding with the shipment of LEM 9 to AMR. Between April of 1967 and the lunar landing flight, LTA-9 would be engaged in operational flight experience and follow-on integrated systems testing in the atmospheric environment. As more experience is acquired with the tethered vehicle, undoubtedly, the scope of its test and operational activities will increase. Along these lines, it is anticipated that the manned spacecraft flights (starting with LEM 5) will broaden the area of utilization for the manned atmospheric flight LEM.

Prior to its delivery to the operational test site, LTA-9 will have completed in-house proof and acceptance testing. These ground tests, as mentioned in section 5.4, constitute constraints on initiation of manned atmospheric flight operations.

LTA-9 structure will be ascertained by imposing proof loads simulating critical conditions. Recorded stress-strain data will be compared with predicted stresses to substantiate analysis and design predictions. The gimbal system will undergo all static and dynamic ground tests to assure that its structural integrity meets design requirements. LTA-9 drop tests will be performed to confirm the integrity of the structure and landing gear prior to operational use. A ground vibration survey will be performed to ascertain LTA-9 modal frequencies and vibratory response.

Development testing and demonstration of the moving support vehicle or facility must be accomplished during the same time span as the LTA-9 subsystem development and proof tests.

The tether support development testing would include confirmation of:

(1) Structural integrity in the LTA-9 test configuration, including static, dynamic and vibratory loadings.

(2) Satisfactory aerodynamic characteristics of the moving support - LTA-9 combination.

(3) Electrical integration and freedom from EMI problems for all LTA-9 assisted operations.

(4) Ability to follow the LTA-9 vehicle dynamics to specified limits.

Assignment of the specific LTA-9 test objectives to either a fixed tethering facility (LRC-type) or a helicopter tether capable of providing the LTA-9 with six degrees of freedom requires consideration of the test benefits as well as the restrictions arising from each method. The fixed or ground tethered method provides for more positive flight safety and the ability to maneuver the vehicle in simulated lunar flight. Furthermore, the evaluation of combined subsystem functional operations, performance and evaluation of given subsystem malfunctions or failures can be studied under the controlled and limited translational conditions inherent in the fixed tethered facility. However, the geometric limits of the ground tethered facility severely limit test capability when translational freedom becomes either a primary test condition or an important over-riding factor in a given test.

The latter consideration applies primarily to achievement of landing radar and IMU test objectives. Also, in the case of sensing and correcting flight control system errors in maneuvering flight and in the landing trajectories, an expanded flight envelope would provide a more realistic operational environment to evaluate potential problems.

In gaining near-operational flight experience with man-in-the-loop, extended flight boundaries without mechanical restraints permit uninterrupted flight control experience in real-time mission sequence hover and landing trajectories.

Precise evaluation of the navigation and guidance subsystem and its interface with the flight control system (particularly, the computer, IMU, landing radar and stabilization and control electronics) requires simulation of the LEM altitude-velocity profile. A helicopter tethered operation at altitude, with non-LEM velocities would accumulate test time on the operating equipment and permit an evaluation of N&G/FCS interfaces and functional sequences even though a true exercise of the combined equipment on a mission profile could not be achieved.

Figure 5.1 illustrates, in schedule format, the test objectives that could be accomplished with a ground tethered facility, the objectives requiring a helicopter tether and the ground tethered test objectives which would be profitably re-investigated in an expanded flight envelope provided by a helicopter tether. Further evaluation of the different tethering methods is presented in Appendix K.

5.8 INSTRUMENTATION AND DATA ACQUISITION

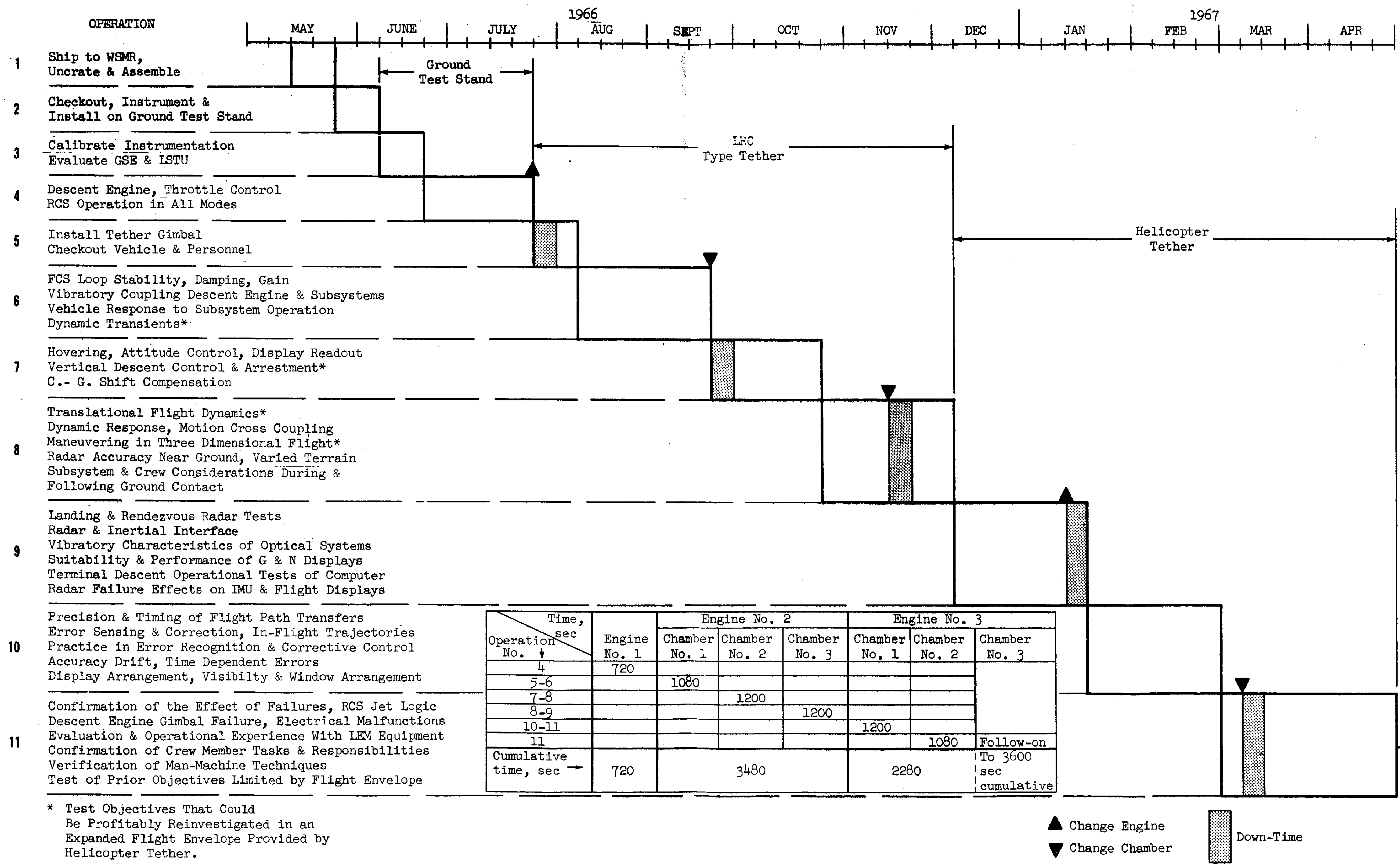
The overall instrumentation approach will be similar to that described in Section 4.7 for LTA-8 in that operational and R & D LEM telemetry and signal conditioning will be utilized. In addition to the telemetered data the onboard LEM magnetic tape equipment will be utilized. In-flight telemetry will be relied upon for safety-of-flight information and magnetic tape will be utilized for detailed post flight data analysis. Onboard photographic coverage, particularly of the LEM controls and displays during powered flight operations, will supplement the analog and digital data. In addition to subsystem performance measurements, the operational flight environment particularly, equipment vibration and thermal response will be monitored.

Preflight and post flight subsystem checkout will be accomplished using the LEM PCM telemetry in conjunction with the LSTU listed in Section 7.

The helicopter-tether operations will require r-f telemetry capability at the test site. Ground-tethered facilities offer the possibility for hardline telemetry transmission to the ground control station. However, it would be more expedient to utilize the r-f links required for the helicopter-tether phase of the LTA-9 activities than to develop and checkout hardline transmission techniques for LTA-9.

While a detailed instrumentation measurement list is premature at this time, it is anticipated that in addition to the LEM/LTA-9 items, status information concerning tether cable dynamics and tether facility, whether helicopter or ground type, will be required.

In order to substantiate flight data during tracking maneuvers and terminal descent optical tracking or vertical photography from the ground will be utilized.



Operation No. ↓ / Time, sec	Engine No. 1	Engine No. 2 Chamber No. 1	Engine No. 2 Chamber No. 2	Engine No. 2 Chamber No. 3	Engine No. 3 Chamber No. 1	Engine No. 3 Chamber No. 2	Engine No. 3 Chamber No. 3
4	720						
5-6		1080					
7-8			1200				
8-9				1200			
10-11					1200		
11						1080	Follow-on
Cumulative time, sec →	720	3480			2280		To 3600 sec cumulative

* Test Objectives That Could Be Profitably Reinvestigated in an Expanded Flight Envelope Provided by Helicopter Tether.

Fig. 5-1 LTA-9 Flight Test Planning

6. RELIABILITY ASSURANCE

6.1 DIRECT APPLICATION TO LEM

The LTA-8 and LTA-9 vehicles will provide an opportunity to conduct an integrated test program which will permit Grumman to correlate test results with actual operational feedback of data prior to manned space flight. No other LTA testing provides the quantity and quality of information which will be available from the combined system LTA-8 and -9 operations. The results obtained from these vehicle tests will furnish the most significant reliability data short of actual lunar descent, at a combination of the highest level of assembly and near-operational use.

Data from the LTA-8/9 program will be correlated with the results of the preceding LTA-4, -5 and -7 tests. For example, the vibration characteristics obtained from actual space simulated descent engine operations on LTA-8 will verify data obtained from the electromechanical shaker vibration tests performed on LTA-4 and -7. Simulated or near-operational landing missions on LTA-9 will provide useful information on subsystem performance while being subjected to rocket engine induced vibration in flight and landing shocks.

Reliability assurance of the propulsion system and the RCS will be measurably increased by the near-operational and repetitive missions of LTA-8/9. Following thrust chamber or engine replacements, after completing a test phase, the reliability data obtained will be correlated with the mission life reliability data obtained from LTA-5 testing and data accumulated by the propulsion and RCS subcontractors. In this manner, the reliability assurance and the engineering confidence in the propulsion system and RCS will be continually upgraded. The reliability aspects of the additional onboard subsystems will be treated in a manner similar to that described for the propulsion and reaction control subsystems.

Reliability personnel will assist in the preparation of test plans for special LTA-8/9 equipment and will monitor both preparatory tests as well as the LTA-8/9 operations. The WSMR operations will be covered full time by an on-site reliability test engineer, whose functions will include:

a) Defining reliability requirements

b) Monitoring all the tests

c) Analyzing test data

d) Failure reporting, preliminary failure analysis and recommended corrective action.

The LTA-8 and -9 operation is the only program where all the interconnected subsystems will be operated in their proper sequences. Each successful flight will add to the engineering confidence of the integrated subsystem operation and demonstrate the ability of man to make a successful lunar landing.

6.2 LTA-8/9 RELIABILITY DEVELOPMENT

Stress-to-failure tests run on equipment qualified for LTA-8/9 use on the safety-of-flight items of the planned flights will uncover failure modes and evaluate safety margins and assure that the LTA-8/9 operations will proceed with a minimum of hazard. Any failure detected during the LTA-8/9 operations can be examined to determine whether the failure mode was one which was observed at higher than mission levels during the stress to failure test. If such is the case, the cause of failure may be traceable to an underestimate of the environment and corrective action can be effective in preventing occurrence on LEM mission flight. If a new or unanticipated failure mode is detected, the failure effect analysis will be rechecked to determine the impact on the overall system reliability.

Malfunctions experienced during the LTA-8/9 program will be investigated to the fullest extent possible. The history of the failed component will be traced back through the development program by way of the "LEM Test Identifications Program". Failure reports will be analysed during the LTA-8/9 program to detect possible wear-out patterns.

One of the major benefits to be derived from the LTA-8 and LTA-9 test vehicles is the development of a measure of the LEM reliability growth. Failure information from these tests will be valuable for design modifications, defining checkout, monitoring and sensing procedures, as well as providing a high degree of confidence in the over-all operational decision rules for the LEM lunar landing mission. This type of empirical data is extremely important since analytic methods have to be used for reliability estimation and failure effect analysis during early design phases. These analyses cannot necessarily consider all possible types of failures in an integrated system, such as wire crossings causing cross-talk, even if there is high confidence in the reliability estimates of the individual components.

7. GROUND SUPPORT EQUIPMENT AND FACILITY REQUIREMENTS

This section defines the support equipment required for LTA-8 and LTA-9 field test operations. An equipment comparison is presented for the following conditions:

1. Restrained LTA-8 firing tests at the propulsion system test facility at WSMR.

2. Tethered tests of LTA-9, for either a fixed tether facility or helicopter-tether method at WSMR.

3. Tethered tests of LTA-9, conducted at the Langley Research Center Lunar Landing Research Facility (LLRF).

The tethered operations also entail prerequisite atmospheric restrained vehicle firings. For WSMR tethered operations such firing would utilize one of the propulsion test stands. At LRC the restrained firing would be performed on the LLRF.

The listing shows the Ground Support Equipment (GSE) available at WSMR as a result of earlier LEM program developments, notably LTA-5 and LEM 1. The additional GSE required for integrated system restrained firings of LTA-8 and the tethered operation of LTA-9 (both the fixed and helicopter approaches) are also tabulated. It is anticipated that one set of GSE would be time-shared between these vehicles if testing were concentrated at the WSMR site. For comparison, the equipment and quantity to support a tethered LTA-9 operation at LRC is tabulated. Some of the less specialized items, particularly, mechanical support equipment may be available at LRC as a result of other NASA (or Langley Air Force Base) programs. However, the majority of the equipment listed, such as the LEM Special Test Units (LSTU) and Maintenance Test Stations (MTS), would be a duplication of equipment that will be available at WSMR for LTA-5, LTA-8 and LEM 1. LSTU are utilized since PACE is not currently scheduled for WSMR.

The column denoted "WSMR-Added Quantity Required", reflects the GSE sharing between the above-mentioned LEM and LTA vehicles at WSMR. The LEM 1 and (backup) LEM-2 launches will have been completed by the end of 1965 when the field operation for LTA-8 is scheduled to begin. LTA-9 test operations commence near the middle of 1966. Therefore, the time scheduling of the combined LEM WSMR operations is conducive to minimizing the need for duplicate GSE.

It should be noted that in any tethered flight operation, the LEM fuel cell electrical power supply would be replaced by conventional battery power as a precautionary flight safety measure.

Additional support considerations for a WSMR fixed tether approach are electrical power supply to operate the tether facility and access roads to the facility.

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COMPARISON OF GSE REQUIRED FOR LRC AND WSMR

SUPPORT EQUIPMENT NOMENCLATURE	SUPPORTED SYSTEM/ SUB-SYSTEM	LRC QTY REQ	WSMR (WHITE SANDS MISSILE RANGE) ADD QTY REQ	AVAIL	Usage LTA-8	Teth'd Usage LTA-9	SUGG'T'D LOCATION (LANGLEY) (WSMR)	REMARKS
Sling, Hoisting, LEM	Structures	1	0	2	1	1	Test/Prep-Static	
Work Stand, LEM	Structures	1	0	2	1	1	Test/Prep	
Dolly Handling LEM	Structures	1	0	2	1	1	Test/Prep-Flite	
Workstand Portable	Structures	1	1	0	0	1	Tether Site	
Transporter A/S	Ascent Stage	1	0	2	1	1	O & C Static	For trans. to site & support restrained firing.
Sling, Hoisting A/S	Ascent Stage	1	0	2	1	1	Static	
Stand, Support A/S	Ascent Stage	1	0	2	1	1	Test/Prep	
Workstand A/S	Ascent Stage	1	0	2	1	1	Test/Prep	
Sling, Tank D/S	Descent Stage	1	0	2	1	1	Test/Prep-Static	
Transporter D/S	Descent Stage	1	0	2	1	1	Test/Prep	
Sling,Hoisting D/S	Descent Stage	1	0	2	1	1	Test/Prep	
Stand, Support D/S	Descent Stage	1	0	2	1	1	Test/Prep	
Stand, Work D/S	Descent Stage	1	0	2	1	1	Test/Prep	
Dolly, Tank D/S	Descent Stage	1	0	2	1	1	Static	
Fixture, Install, Engine D/S	Engine	1	0	2	1	1	Test/Prep Static	Modified for Short Engine
Fixture, Install, Engine A/S	Engine	0	0	2	1	0	Test/Prep Static	Modify for Pick-up Points
Dolly, Engine D/S	Engine	1	0	2	1	1	Test/Prep Static	Modify for Pick-up Points
Dolly, Engine A/S	Engine	0	0	2	1	0	Test/Prep Static	Modify for Pick-up Points
Sling, Hoist, Engine D/S	Engine	1	0	2	1	1	Test/Prep Static	Modify for Pick-up Points
Sling,Hoist, Engine A/S	Engine	0	0	2	1	0	Test/Prep Static	Modify for Pick-up Points
Covers, Engine	Engine	1	0	2	0	1	Tether Flite	
Sling RCS	RCS	1	0	2	1	1	Test/Prep Static	
Dolly RCS	RCS	1	0	2	1	1	Test/Prep Static	For O & C Static Only
Cover RCS	RCS	1	1	0	0	1	Tether Flite	4 covers to 1 Set
Adapter Stand, Firing	LEM Struc/Propulsion	0	0	4	1 Set	1*	Static	*Modified Soft Mount only - LTA-9
Kit, Tool	Structure	1	2	0	1	1	All Areas	
Ladder Boarding	Structure	1	1	0	0	1	Tether Flite to Board LTA-9	

COMPARISON OF GSE REQUIRED FOR LRC AND WSMR

SUPPORT EQUIPMENT NOMENCLATURE	SUPPORTED SYSTEM/ SUB-SYSTEM	LRC	WSMR (WHITE SANDS MISSILE RANGE)				SUGG'T'D LOCATION (LANGLEY) (WSMR)	REMARKS
		QTY REQ	ADD QTY REQ	AVAIL	Usage LTA-8	Teth'd Usage LTA-9		
Van, Maintenance	Structure	1	1	0	0	1	Tether Flite	For quick repair (line maintenance)
Cart Air Condition	Structure	1	0	2	1	1	All Areas	GFE Equipment Storage
Crane 8-ton Mobile	Structure	1	1	0	0	1	Tether Recovery	GFE
Tethering Rig	Structure	0	1	0	0	1	Tether	GFE
Helicopter	Structure	0	1	0	0	1	Flight Recovery	GFE: #Available @ Langley
Covers, Protective	A/S & D/S	1	0	2 ea	1	0	Test/Prep	GFE, 20,000 lb Lift Cap.
Kit, Safety	Personnel	1	2	0	0	1	Static	For Protection when Transporting A/S & D/S To Static & Site
Mat, Ground	Structure	1	1	0	0	1	Tether Flite	
Crane, Overhead	Structure	1	0	2	1	1	Recovery	Free Flite Landing & Tether Area
Power, Ground, Mobile	Structure	1	1	0	0	1	Static Test/Prep	GFE
Tethering Yoke Work Stand	Structure	1	1	0	0	1	Field	GFE
Tie Downs, Restrained Firing	Structure	1	0	0	0	0	Tether & Flight Tether	For Attaching Harness to Rig or Copter GFE @ Langley-Avail @ WSMR.Simulate
Apparatus, Fire	Structure	1	1	0	0	1		Restrain Flite on Tether Rig
Alignment Equip. Optical	Guidance System	1	0	1	1	1	Tether Flite	GFE
Cherry Picker	Structure	1	1	0	0	1	Test/Prep	Alignment of LTA-8, -9 Guidance System
Struts, Jury	Structure	1 set	1 set	0	0	1	Flite	GFE
Sling, Fuel Tank, A/S	A/S Tank	0	0	2	1	0	Test/Prep Flite	LTA-9
							Test/Prep	Maint. for All Vehicles
Sling, Oxidizer Tank, A/S	A/S Tank	0	0	2	1	0	Static	Maint. for All Vehicles
Dolly, Tank Handling A/S	A/S Tank	0	0	2	1	0	Test/Prep	Maint. for All Vehicles
							Test/Prep	Maint. for All Vehicles
Cart, Fuel Storage & Transfer	Propulsion & Reaction Control	1	0	1	1	1		GFE
Cart, Oxidizer Storage & Transfer	Propulsion & Reaction Control	1	0	1	1	1		GFE
Conditioner, Fuel Temp	Propulsion & Reaction Control	1	0	1	1	1	Flite	
Conditioner, Oxidizer Temp	Propulsion & Reaction Control	1	0	1	1	1	Flite	
Cart, Fuel, Purge & Flush	Propulsion & Reaction Control	1	0	2	1	1	Flite	
Cart, Oxidizer Purge & Flush	Propulsion & Reaction Control	1	0	2	1	1	Flite	

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COMPARISON OF GSE REQUIRED FOR LRC AND WSMR

SUPPORT EQUIPMENT NOMENCLATURE	SUPPORTED SYSTEM/ SUB-SYSTEM	LRC	WSMR (WHITE SANDS MISSILE RANGE)				SUGG'T'D LOCATION (LANGLEY) (WSMR)	REMARKS
		QTY REQ	ADD QTY REQ	AVAIL	Usage LTA-8	Teth'd Usage LTA-9		
Storage, Helium, Low Pressure		1	0	1	1	1	Test/Prep	
Supply, Helium, H.P. Conditioned	Reaction Control	1	0	1	1	1	Flite	
Cart, Check-out, Propul-	Propulsion	1	0	2	1	1	Flite	
Cart, Checkout, RCS	Reaction Control	1	0	2	1	1	Flite	
Adapters, Restrained Firing		0	1	0	1	1	Firing	LTA-8 Only
Adapters, Tethered Firing		1	1	0	1	1	Flite	
Test Stand Substitute Fuel Components	Propulsion Reaction Control	1	0	1	1	1	Test/Prep	
Test Stand, Substitute Oxidizer Components	Propulsion Reaction Control	1	0	1	1	1	Test/Prep	
Test Stand, Helium Components	Propulsion Reaction Control	1	0	1	1	1	Test/Prep	
Disposal Unit, FuelVapor	Propulsion	1	0	1	1	1	Flite	
Disposal Unit, Oxidizer Vapor	Propulsion Reaction Control	1	0	1	1	1	Flite	
Cart, Service, Water Glycol	Environmental Control System	1	1	1	1	1		
Unit, Transfer, Freon	Environmental Control System	1	1	1	1		Launch	GFE
Cart, Leak Tester	Environmental Control System	1	1	0	1	1	Launch	GFE
Adapters, GSE	Environmental Control System	1	1	1	1	1	Launch	GFE
Unit, Transfer, Nitrogen		1	1	0	1	1	Test/Prep	Required to Adapt Test Stand for LTA-9 RCS Version
Unit, Transfer, Oxygen	Environ. Control	1	1	0	1	1		
Storage, Oxygen	Environmental Control System	1	1	0	1	1		GFE
Fluid Supplies	Environmental Control System	1	0	1	1	1		
Unit, Transfer, LH_2	Environmental Control System	1	2	1	1	1	Launch, Test/ Prep	Unless Supplied By Facilities
	Electrical Power System	0	0	1	1	0	Firing	Batteries Replace Fuel Cells For Tethered Operation
Unit, Transfer, LO_2	Electrical Power System	0	0	1	1	0	Firing	" "
Storage, Nitrogen	Environ. Control	1	0	1	1	1		

COMPARISON OF GSE REQUIRED FOR LRC AND WSMR

SUPPORT EQUIPMENT NOMENCLATURE	SUPPORTED SYSTEM/ SUB-SYSTEM	LRC	WSMR (WHITE SANDS MISSILE RANGE)				SUGG'T'D LOCATION (LANGLEY) (WSMR)	REMARKS
		QTY REQ	ADD QTY REQ	AVAIL	Usage LTA-8	Teth'd Usage LTA-9		
Cart, Storage & Converter LH_2	Electrical Power System	0	1	1	1	0	Firing Test/Prep	Batteries Replace Fuel Cells For Tethered Operation
Cart, Storage & Converter LO_2	Electrical Power System	0	1	1	1	0	Firing Test/Prep	" "
Console, Remote Control	Electrical Power System	0	1	1	1	0	Firing	" "
Unit, Pressurization, N_2	Electrical Power System	0	1	1	1	0	Firing	" "
Bench, Check-Out, Supercritical O_2	Electrical Power System	0	0	1	1	0	Test/Prep	The EPS c/o Area Will Not Be In Or Near the PREP Bldg. It Will Be In A Remote Area Due to The Hazards Involved.
Bench, Check-out, Supercritical H_2	Electrical Power System	0	0	1	1	0	Test/Prep	" "
Unit, Service, Water Glycol	Electrical Power System	0	0	1	1	0	Test/Prep	" "
Detector, Leak, Helium	Electrical Power Subsystem	0	0	1	1	0	Firing Test/Prep	Batteries Replace Fuel Cells On Tethered Operation
Storage, Oxygen	Electrical Power Subsystem	0	0	1	1	0	Remote	Facility Item
Storage, Hydrogen	Electrical Power Subsystem	0	0	1	1	0	Remote	Facility Item
Equipment, Detection	Electrical Power Subsystem	0	0	1	1	0	Test/Prep	Facility Item
LSTU, Gyro	Stabil. & Control	1	1	1	1	1	Test/Prep Flite	
LSTU, Programmer & Timer	Stabil. & Control	1	1	1	1	1	Test/Prep Flite	Prior Use - LEM #1
LSTU, Power Supply	Stabil. & Control	1	1	1	1	1	Test/Prep Flite	One Set
LSTU, Descent Engine Control	Stabil. & Control	1	1	1	1	1	Test/Prep Flite	
LSTU, Control Elect. Section	Stabil. & Control	1	1	1	1	1	Test/Prep Flite	
LSTU, Altitude Radar	Nav. & Guidance	1	1	1	1	1	Test/Prep Flite	
LSTU, Digital Timing Unit	Instrumentation	1	1	0	1	1	Test/Prep Flite	
LSTU, In-Flight Test Sys.	Instrumentation	1	1	0	1	1	Test/Prep Flite	

COMPARISON OF GSE REQUIRED FOR LRC AND WSMR

SUPPORT EQUIPMENT NOMENCLATURE	SUPPORTED SYSTEM/ SUB-SYSTEM	LRC	WSMR (WHITE SANDS MISSILE RANGE)				SUGG'T'D LOCATION (LANGLEY) (WSMR)	REMARKS
		QTY REQ	ADD QTY REQ	AVAIL	Usage LTA-8	Teth'd Usage LTA-9		
LSTU, PCM	Instrumentation	1	1	0	1	1	Test/Prep Flite	
LSTU, Data Storage	Instrumentation	1	1	0	1	1	Test/Prep Flite	
LSTU, Signal Conditioning	Instrumentation	1	1	0	1	1	Test/Prep Flite	
LSTU, Transducers & Sensors	Instrumentation	1	1	0	1	1	Test/Prep Flite	
LSTU, Power Supply	Power Subsystem	0	0	1	1	0	Test/Prep Flite	Batteries Replace Fuel Cells for Tethered Operation
LSTU, Displays & Control Meters	Displays & Controls	1	1	0	1	1	Test/Prep Flite	
LSTU, UHF Transponder	Communications	1	1	0	1	1	Test/Prep Flite	
LSTU, PMP	Communications	1	1	1	1	1	Test/Prep Flite	
LSTU, Antenna	Communications	1	1	0	1	1	Test/Prep Flite	
LSTU, VHF Transcvr	Communications	1	1	0	1	1		
LSTU, Audio Center	Communications	1	1	0	1	1		
MTS, Nav. & Guid	Nav. & Guidance	1	1	0	1	1		
MTS, Gyro	Stabil. & Control	1	0	1	1	1		
MTS, Prog. & Timer	Stabil.& Control	1	0	1	1	1		
MTS, Power Supply	Stabil.& Control	1	0	1	1	1		
MTS, Descent Engine Control	Stabil.& Control	1	0	1	1	1		
MTS, Control Electrical Section	Stabil. & Control	1	0	1	1	1		
MTS, Altitude Radar	Altitude Radar	1	0	1	1	1		
MTS, PCM	Instrumentation	1	1	0	1	1		
MTS, Data Storage Equip.	Instrumentation	1	1	0	1	1		
MTS, Signal Condit'g Equip.	Instrumentation	1	1	0	1	1		
MTS, Fuel Cell	Electrical Power	0	1	0	1	0		Batteries Replace Fuel Cell for Tethered Operation
MTS, Power Distribution	Electrical Power	1	1	0	1	1		
MTS, Inverter	Electrical Power	1	1	0	1	1		
MTS, Battery	Electrical Power	1	1	0	1	1		
MTS, Electrical Supervisory	Electrical Power	1	1	0	1	1		
Console, Checkout	Environmental Control	1	0	1	1	1		
Test Stand, Water Glycol Components	Environmental Control	1	0	1	1	1		
Test Stand, Water Components	Environmental Control	1	0	1	1	1		
Test Stand, Gaseous Components	Environmental Control	1	0	1	1	1		
Test Stand, Electrical Components	Environmental Control	1	0	1	1	1		
Simulator, Suit Circuit	Environmental Control	1	0	1	1	1		

COMPARISON OF GSE REQUIRED FOR LRC AND WSMR

SUPPORT EQUIPMENT NOMENCLATURE	SUPPORTED SYSTEM/ SUBSYSTEM	LRC QTY REQ	WSMR (WHITE SANDS MISSILE RANGE) ADD QTY REQ	AVAIL	Usage LTA-8	Teth'd Usage LTA-9	SUGG'T'D LOCATION (LANGLEY) (WSMR)	REMARKS
MTS, Ball Attitude Indic.	Displays & Controls	1	1	0	1	1		
MTS, Flight Controls	Displays & Controls	1	1	0	1	1		
MTS, Radar & Power	Displays & Controls	1	1	0	1	1		
MTS, Stab. Nav. & Guid.	Displays & Controls	1	1	0	1	1		
MTS, Communications	Displays & Controls	1	1	0	1	1		
MTS, PMP	Communications	1	1	0	1	1		
MTS, UHF Transponder	Communications	1	1	0	1	1		
MTS, Audio Center	Communications	1	1	0	1	1		
MTS, Antenna	Communications	1	1	0	1	1		
MTS, Transceiver	Communications	1	1	0	1	1		
Data Reduction & Display Equipment	Communications	1	0	1	1	1	Test/Prep Flite	Assumed part of Data Acquisition System
Telemetry Ground Station	Communications	1	1	0	[illegible]	1	Test/Prep Flite	Assumed GFE
Calibration Masters, Propellant Flow	A/S & D/S Engine Test Support; RCS Support	1	0	1	1	1	Prop/Firing Flite	
Viscometer	Flowmeter Calibrations	1 set	0	1 set	1	1	Prop Firing Flite	
Densitometer	Flow & Quantity Calibrations	1 set	0	1 set	1	1	Prop Firing Flite	
Conditioning Unit, Propellant	Flowmeter Calibrations	1	0	1	1	1	Prop Firing Flite	
Capacitor, Precision	Calibration	2	0	2	1	1	Prop Firing Flite	
Tester, Capacitor	Calibration	1	0	1	1	1	Prop Firing Flite	
PAM Decommutator	Data Acquisition	1	1	0	0	1		
	Temperature Calibration							
Heat Sink, Oil Bath, 500 °F	Immersion-type Thermostatic Control	1	0	1	1	1	Test/Prep.	Calibration
Master Thermometers (38 °C - 405 °C)	Thermometer Calibration	1 set	0	1 set	1	1		
Furnace, High Temperature	Thermocouple Calibration	1	0	1	1	1		

COMPARISON OF GSE REQUIRED FOR LRC AND WSMR

SUPPORT EQUIPMENT NOMENCLATURE	SUPPORTED SYSTEM/ SUB-SYSTEM	LRC	WSMR (WHITE SANDS MISSILE RANGE)				SUGG'T'D LOCATION (LANGLEY) (WSMR)	REMARKS
		QTY REQ	ADD QTY REQ	AVAIL	Usage LTA-8	Teth'd Usage LTA-9		
	Temperature Calibration - cont.							
Master Thermocouples	Thermocouple Calibration (High Temp)	1 set	0	1 set	1	1	Test/Prep	
Potentiometer, Millivolt Readout	Thermocouple Calibration (High Temp)	1	0	1	1	1	Test/Prep	
Medium Low Temperature	Temperature Calibration (Below Ambient)	1	0	1	1	1	Test/Prep	
Measuring Std, Low Temperature .	Low Temperature, Medium Measurement	1	0	1	1	1	Test/Prep	
	Pressure Calibration							
Tester, Dead Weight 250 - 10,000 psi	Gauge Checkout & Calibration	1	0	1	1	1	Test/Prep	
Master Pressure Gauges, Portable	Checkout & Calibration of Pressure Transducers	1	0	1	1	1	Test/Prep	On-Site Checkout of Gauges and Transducers.
McLeod Gauge	Calibration of Low Pressure Gauges	1	0	1	1	1	Test/Prep	
Pump, Vacuum	Low Pressure Calibration	1	0	1	1	1	Test/Prep	
	Flow Calibration							
Stand, Calibration, Fluid Flow	Calibrate & Checkout of Flow Meters	1	0	1	1	1	Test/Prep	
Std, Secondary Calibration, Gox, & Fluid Source	Calibrate & Checkout of Flow Meters	1	0	1	1	1	Test/Prep	
Master Flowmeters	Gas Flowmeter Checkout & Calibration	1 set	0	1	1	1	Test/Prep	
Master Pneumatic Gauges	Monitor Pressure	1	0	1	1	1	Test/Prep	
	Miscellaneous							
Measuring Instrument, Master Humidity	Humidity Indicators	1	0	1	1	1		

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COMPARISON OF GSE REQUIRED FOR LRC AND WSMR

SUPPORT EQUIPMENT NOMENCLATURE	SUPPORTED SYSTEM/ SUBSYSTEM	LRC	WSMR (WHITE SANDS MISSILE RANGE)				SUGG'T'D LOCATION (LANGLEY) (WSMR)	REMARKS
		QTY REQ	ADD QTY REQ	AVAIL	Usage LTA-8	Teth'd Usage LTA-9		
	Miscellaneous - cont.							
Precision Weight & Balance	Scale Calibrations	1 set	0	1	1	1		
Leak Detector Masters, Fuel, Oxidizer, Gas	Checkout & Calibration	1 set	0	1	1	1		Checkout & Calibrate Fuel, Oxidizer, Helium & Hydrogen Leak Detectors.
Dynamometer, Thrust Load Cell	Thrust Cell Calibration	1	0	1	1	1		
Morehouse Proving Rings, 1000#, 5000#, 20,000#	Thrust Cell Calibration	1 set	0	1	1	1		
Data Acquisition System	All Tests	1	0	1	1	1		System being provided at WSMR for Propulsion Tests.
Generator, Time Mark TEK 180B	Oscilloscopes	1	0	1	1	1	Test/Prep	This and Subsequent for Electronic Checkout.
Generator Signal TEK 190B	Oscilloscopes	1	0	1	1	1	Test/Prep	
Termination, Std	Oscilloscopes	1	0	1	1	1	Test/Prep	
Voltmeter, D.C. HP 425	Oscilloscopes, Frequency Counter, D.C. Motors	1	0	3	1	1	Test/Prep	
Voltmeter, A.C. HP 400H	Oscilloscopes, Frequency Counter, A.C. Motors	1	0	3	1	1	Test/Prep	
Oscillator, Audio HP 200CD	Isolation Transformer, Ratio Bridge	1	0	2	1	1	Test/Prep	
Transformer, Ratio, Gertch 1001	Isolation Transformer, Ratio, Bridge	1	0	1	1	1	Test/Prep	
Power Supply, D.C. Hintel 302	Ratio Bridge, D.C. Motors, Decade Divider	1	0	1	1	1	Test/Prep	
Transformer, Isolation, Gertch ST200A	Ratio Bridge, Pots, Decade Divider	1	0	2	1	1	Test/Prep	
Counter, Frequency HP 5245	Phase Generator, Square Wave Generator	1	0	2	1	1	Test/Prep	
Calibrator, VTVM HP 738	Phase Generator, A.C. VTVM, A.C. Motor	1	0	1	1	1		
Test Set, Frequency Response, HP 739	Differential Voltmeter	1	0	1	1	1		
Oscillator, HP 200SR	A.C. VTVM	1	0	2	1	1		
Voltmeter, RF	Signal Generator	1	0	1	0	1		
Analyzer, Distortion HP 330D	Phase Generator, RF Power Meter	1	0	1	0	1		

COMPARISON OF GSE REQUIRED FOR LRC AND WSMR

SUPPORT EQUIPMENT NOMENCLATURE	SUPPORTED SYSTEM/ SUBSYSTEM	LRC QTY REQ	WSMR (WHITE SANDS MISSILE RANGE) ADD QTY REQ	AVAIL	Usage LTA-8	Teth'd Usage LTA-9	SUGG'T'D LOCATION (LANGLEY) (WSMR)	REMARKS
Oscilloscope/Plug-In TEK 545A	Scope, Phase Generator, Servo Scope	1	0	1	1	1		
Bridge, Synchro ESI 2¼	Synchros, Multiplexer	1	0	3	1	1		
Load Bank	Synchros, Multiplexer	1	0		1	1		
Regulation Monitor, Calibration Std Corp	Power Supplies	1	0	4	1	1		
Cell Bank, Std, NLS	DVM	1	0	1	1	1		
Voltage Divider, Special ESI	DVM	1	0	1	1	1		
Phase Standard Action Labs	Phase Measuring Equipment	1	0	1	1	1		
Digital Voltmeter (Ratio & A.C.) Cimron 7400	AC/DC Motors Differential Voltmeter	1	0	1	1	1		
Millivolt Source L & N 8662	Pen Recorder, Pulse Generator	1	0	1	1	1	Test/Prep	
Clinometer Hilger & Watts	Tilt Table	1	0	1	0	1	Test/Prep	
Theodolite Weld, Heerberg	Precision Tables, Tilt Tables	1	0	1	0	1	Test/Prep	
Synchro & Dials (26V & 115V)	Indicators	1	0	3	0	1	Test/Prep	
Signal Generator, FM Marconi	FM Receiver, Multiplexer	1	0	1	0	1	Test/Prep	
Dummy Loads	Power Supplies	1	0	3	1	1	Test/Prep	
Power Meter HP 431B	RF Power Meter	1	0	1	0	1	Test/Prep	
Detector Mount	Coaxial or Waveguide Instruments	1	0	4	4	1	Test/Prep	
WOW Meter	Power Supply	1	0	1	1	1	Test/Prep	
Power Meter Audio Output (GR)	FM Receiver	1	0	1	0	1	Test/Prep	
Decade Resistors GR 1432	Phase Voltmeter, Fuel Quantity Indicator	1	0	3	1	1	Test/Prep	
Block Levels Hilger & Watts	Tilt Tables	1	0	2	0	1	Test/Prep	
Oscillators, Transfer HP 540B	Mixer	1	0	2	1	1	Test/Prep	
VTVM A.C.	Voltages, Resistances	1	0	2	1	1	Test/Prep	
EPUT Meter Berkeley	Frequency, Speed, Time Interval	1	0	1	1	1		
Attenuator	Attenuation & Gain Measurements	1	0	4	1	1		

COMPARISON OF GSE REQUIRED FOR LRC AND WSMR

SUPPORT EQUIPMENT NOMENCLATURE	SUPPORTED SYSTEM/ SUBSYSTEM	LRC. QTY REQ	WSMR (WHITE SANDS MISSILE RANGE) ADD QTY REQ	AVAIL	Usage LTA-8	Tetn'd Usage LTA-9	SUGG'T'D LOCATION (LANGLEY) (WSMR)	REMARKS
Variac GR W10MT3A	Variable Input Voltages	1	0	1	1	1		
Milliammeter, Volt Amp Sensitive Research	Voltage, Current	1	0	1	1	1		
Shunts, L & N	Current Measurement	1	0	4	1	1		
Wheatstone Bridge, L & N	Capacitators, Resistors	1	0	1	1	1		
Impedance Bridge ESI	Impedance of Reactive Components	1	0	1	1	1		
Wave Analyzer HP 302A	Measure & Analyze Fundamental, Harmonics & Intermodulation Characteristics	1	0	1	1	1		
Frequency Converter	Extend Frequency Counter Range	1	0	2	1	1		
Video Amplifier Plug-in	Increase Frequency Counter Sensitivity	1	0	2	1	1		
Power Amplifier	Wattmeters & High Power Voltmeter	1	0	1	1	1		
Potentiometer, L & N	Transducers	1	0	4	1	1		
Indicator, Standing Wave HP 415B	SWR and NULL Measurements	1	0	1	0	1		
Nullmeter, Phazor	Phase & NULL Measurements	1	0	1	1	1		
Power Supply, A.C. Holt AV 323	Low Level Amplifier	1	0	1	1	1		
Decade Resistor, Power Clarostat'	High Power Loads	1	0	1	1	1		
Period Multiplier	Extend Range of Frequency Counter for Period Measurements	1	0	1	1	1		
Voltage Regulator	Line & Input Regulation	1	0	2	1	1		
Tester, Transistor	Transistors	1	0	1	1	1		
Discriminator, Subcarrier	FM Discrimination	1	0	1	0	1		
Power Meter, RF Termaline	RF Power Measurements	1	0	1	0	1		
Capacitor, Precision	Fuel Quantity Indicator	1	0	3	1	1		
Shaker, Unholtz-Dickie	Transducers, Vibration Pickups	1	0	1	1	1		
"G" Table (Centrifuge) Genisco	Accelerometers	1	0	1	1	1		
Voltage Divider Lead Compensator, ESI LC 875B	Linear Potentiometers	1	0	1	1	1		
Multimeter Simpson 270	Standard Lab Measurements	1	0	5	1	1		
Rate Table Genisco	Rate Transducers	1	0	1	1	1		

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8. REFERENCES

1. MSC letter SLM-63-90, 23 April 1963 and enclosure: "Minutes of Meeting", GAEC Presentation on LTA-9 Progress Summary.

2. GAEC Report LED-470-2, 15 May 1963: "Application of LEM technology to NASA Lunar Landing Research Program".

3. Sikorsky Aircraft: "Preliminary Technical Study of the Lunar Excursion Module Simulated Lunar Performance using a Sikorsky S-64 Crane Helicopter".

4. Lear Siegler Astrionics Division Proposal AD-645(P), 11 February 1963: "Preliminary Engineering Proposal for a Lunar Landing and Rendezvous Docking System".

5. GAEC Report LPL-600-1, 15 May 1963: "The Test Plan for the Lunar Excursion Module Project Apollo".

6. Burns & Roe Report LED-2-1 - Part II, 15 May 1963: "Conceptual Design Study and Design Criteria for the LEM Propulsion Test Facility".

7. GAEC Report LPL-480-1, 15 May 1963: "Training Plan for the Lunar Excursion Module, Vol. I, Flight Crew Training".

8. GAEC Report LED-470-1, 15 March 1963: "LTA-9 Feasibility Study Report".

APPENDIX A

ATMOSPHERIC OPERATING CONDITIONS

This appendix compares the differences in conditions under which a LEM in spaceflight and an atmospheric flight LEM operate. The LTA-9 atmospheric vehicle operating conditions can be compared with the space LEM in the areas of matching LEM handling characteristics and trajectory envelopes, simulation of the lunar environment, payload capability and completeness of the system. The ability to provide advanced astronaut operational experience for the terminal descent phase of the lunar mission is closely associated with the preciseness of simulation. However, the primary objectives of the proposed LTA-9 are test oriented rather than directed toward precision training.

The major differences in handling characteristics arise from the difference between earth and lunar gravitation and from aerodynamic forces and moments. The tethered LTA-9 operation is directed toward minimizing these difference by utilizing the tethering device to provide 5/6 of the LTA-9 weight and by restricting LTA-9 airspeed. Below a nominal velocity of 25 fps the lunar-earth translational acceleration difference due to aerodynamics is negligible (or the order of 0.005 g's) and only the gravity consideration is important. Discussion of the ability of various tethered approaches are treated in the body of the report and in appendices C through E, G, and K.

LEM rocket engine operations are degraded by atmospheric operation to the extent that the maximum thrust of the 10500 lb. thrust descent engine is reduced to, nominally, 7000 lbs. The 100 lb. thrust reaction control rocket thrust is reduced to approximately 57.5 lbs. Atmospheric pressure will, of course, necessitate modification to the LEM's Environmental Control Subsystem water boil-off section.

The tethered LTA-9 configuration will, however, be quite similar to the basic LEM since:

*Payload Capability: includes all equipment, especially rocket propulsion, RCS and flight control electronics used during the lunar terminal descent.

*Crew Station Provision: controls, displays, and visibility are essentially identical to LEM.

Atmospheric flight cannot provide the thermal-vacuum conditions of the lunar mission. The effects of these conditions in conjunction with lunar gravity cannot be simulated in earth landings. Specifically, rocket plume effects, dust blow-up, and near-surface vehicle effects are different.

In earth landings the visual requirements can be brought to within a tolerable lighting simulation by scheduling WSMR flight operations of LTA-9 near dawn or in twilight (i.e. this would be compatible with other operational considerations such as wind and temperature conditions at WSMR). Section 9.3 of the original LTA-9 feasibility study report, reference 8., summarizes the optics and lunar lighting simulation aspects.

The capability offered by an atmospheric tethered flight LEM may be summarized as follows:

1. Ability to operate LEM descent engine simulating LEM mechanical power in the landing phase.

2. Ability to operate the modified but integrated LEM subsystems prior to space flight on a regular basis of operation, analysis and inspection, upgrading and operation again.

3. Ability to investigate LEM trim, moment and flight control functions with minimum side effects.

4. Ability to operate at nominal speeds (below 25 fps aerodynamic effects are low) for practical test run durations over a sizeable altitude, lateral and longitudinal flight space for terminal descent trajectory flight experience.

5. Ability to operate an integrated LEM system in flight, which although modified, is a complete LEM.

6. Crew and vehicle flight safety.

It is recognized that subsystem modifications will result in differences in actual system performance of LEM hardware and the degree of evaluation of a particular component or assembly may be less than optimum. However, functional flight control subsystem operations are of great importance and are attainable with tethered LTA-9 flight. The direct correlation of, for example, vibration, thermal interaction and closed loop stability sensitivity test data will be complemented with analysis of any off-design condition induced by the atmospheric operation.

APPENDIX B

SUBSYSTEM MODIFICATIONS REQUIRED

B.1 SUMMARY OF MODIFICATIONS

The subsystem modification criterion for both LTA-8 and LTA-9 is that of minimum departure from the LEM. The partial vacuum testing environment of LTA-8 results in no modification to the basic subsystems other than removal of the LEM landing gear to permit installation in the WSMR test stand. Instrumentation requirements necessitate the use of a LEM R&D telemetry package to complement the operational PCM system. The manned atmospheric operation of LTA-9 primarily necessitates modifications in the Propulsion, Reaction Control, Environmental Control subsystems and making the landing gear suitable for repeated, manned landings. Figure B-1 presents a schematic of the basic LEM.

The subsystem modifications required for the successful performance of the restrained firing tests of integrated system test vehicle, LTA-8 and the manned tethered dynamic tests of LTA-9 are summarized below.

Structure. The major structural changes consist of interface structural design between the descent stage hard points and the tether gimbal assembly. Provisions for manned safety will be required in the form of an auxiliary safety line in the ascent stage to facilitate pilot removal. Descent stage heat protection for LTA-9 will require a heat shield to protect the descent stage engine well.

Stabilization and Control. No changes are anticipated in the design of the S&C subsystem; however, electrical gain and balance changes will be introduced in the sections or assemblies where atmospheric flight dictates changes (i.e., accelerometer circuitry).

Navigation and Guidance. Modifications in N&G electronics are required for the same reasons given under S&C. In addition, the earth flight environment of LTA-9 may require local structural upgrading of radar antennas and gimbals. Since the radar is generally a velocity sensitive device, operation of the LEM radars in atmospheric flight will not require significant changes.

Crew Systems. LEM controls and displays will be maintained throughout. In lieu of modifications, off-loading of non-essentials and lunar stay expendables is in order (i.e., motion picture cameras, food, water, first aid equipment).

Landing Gear. While the landing gear for LTA-8 is completely removed to enable test stand installation, LTA-9's will be modified by installing footpads capable of repeated earth landings. The LEM honeycomb shock absorber cartridges will be replaced after each flight.

Instrumentation. Test instrumentation for LTA-8 and LTA-9 includes the installation of both operational and R&D instrumentation equipment. The lunar scientific equipment will be omitted and some modification or off-loading in the In-Flight Test System (IFTS) may be in order since LTA-9 flight time is on the order of minutes rather than lunar mission duration.

Communications. The lunar-earth section of the communications subsystem will be eliminated from the communications subsystem. The television link is another non-essential for the LTA-9 flight objectives and will be off-loaded.

Electrical Power. The electrical power distribution system will be essentially identical to LEM. Where electronic components are off-loaded as non-essential, replacement with an electrically equivalent load will be effected. The fuel cell power generation section in LTA-9 will be replaced with a battery supply to expedite flight operations and minimize flight hazards. LTA-8, however, will employ the LEM fuel cells.

Environmental Control Subsystem. The LTA-8 ECS will be complete even though all testing will be unmanned. The minimum modifications for LTA-9 includes resizing all fans for atmospheric conditions, either by fan blade redesign and/or installation of a motor power limiter. All pressure sensors will be modified to operate as a function of earth ambient pressure rather than the absolute pressure schedule associated with space flight operations. A differential pressure adjustment in the cabin pressure relief valve will also be required.

Substitution of freon for water as a heat sink fluid is also required together with the addition of freon flow control valving to meter freon flow to the boiler. Water from the water separator will be jettisoned.

In the unpressurized suit operating mode, the cabin will be air-filled with 100% oxygen in the make-up pressure supply tanks. Pressurized suit operations will be conducted with an air-filled cabin and a mixture of oxygen and nitrogen in the make-up supply pressure tank.

Propulsion and RCS. LTA-8 rocket engine operation in the WSMR partial vacuum propulsion test chamber will require no modification. The atmospheric operation of LTA-9 will require a modified descent engine and modified reaction control thrusters.

Primary modification to both propulsion and RCS is the reduction of nozzle expansion ratio by shortening the nozzle to prevent flow separation. Modification to engine throttling is also required. No changes will be made to combustion chamber or throat geometry. Since the LTA-9 flight operations do not require ascent engine firing, a dummy ascent engine will be installed.

Since the satisfactory operation of the LEM descent engine and RCS in the atmosphere is paramount, the following section considers the modification of these rocket engines in greater detail.

B.2 EFFECTS OF ATMOSPHERIC OPERATION ON PROPULSION SUBSYSTEM

Use of the LEM propulsion system in an atmospheric vehicle requires a number of modifications to various sub-system components to provide satisfactory operation. These modifications in turn affect the performance of the system to such an extent that the operating characteristics in the atmosphere are substantially different from those of the LEM in vacuum.

The major change required for atmospheric operation consists of reducing the engine nozzle expansion ratio to a much lower value than is used in vacuum. This is necessary to prevent flow separation due to over-expansion in the nozzle. The separation phenomena introduces the following characteristics:

a) Possibility of skirt collapse.
b) Unpredictable and inconsistent thrust magnitude and direction.
c) Very inefficient engine operation - low thrust and specific impulse values.
d) Erratic engine throttling performance.
e) Possible destruction of ablative material.

Thus, since separation due to over-expansion is definitely not acceptable, the engine nozzle must be modified to reduce the expansion ratio. The selection of an acceptable expansion ratio for atmospheric operation depends upon the desired engine operating characteristics as well as the ambient pressure. For a fixed thrust engine, a sensible ground rule may be to use an expansion ratio to produce a maximum thrust coefficient for a given chamber and ambient pressure. This would result in the maximum thrust that can be achieved and would correspond to an exit-to-ambient pressure ratio of unity ($Pe/Pa = 1.00$).

It should be noted that even the selection of the optimum thrust coefficient will produce an atmospheric thrust level which is below that which can be achieved in a vacuum with the same chamber pressure. This is illustrated in Figure B-2 which presents a theoretical rocket nozzle performance map. Point "A" corresponds to the thrust coefficient attainable in a vacuum ($Pa = 0$) for a given expansion ratio. If this engine is operated at some atmospheric pressure without charge of expansion ratio, the operating point will shift to point "B". This point lies in the highly over-expanded region of the map where flow separation is certain to occur and also corresponds to a very low thrust coefficient.

To remedy both these conditions requires a reduction of the expansion ratio (cutting off the nozzle). The maximum thrust that can be attained at this Pc/Pa ratio occurs if the nozzle is cut back to a value corresponding to the optimum thrust coefficient (Point "C"). This point lies on the line of maximum thrust coefficient, corresponding to a Pe/Pa = 1.0. It is obvious from the figure that the thrust coefficient, and therefore the thrust at atmospheric pressure (Point "C") will fall below of the value in a vacuum (Point "A").

The only way that the atmospheric thrust can be maintained at its vacuum value is by an increase in chamber pressure and/or throat area. Either one of these modifications affect the injector and chamber design to such an extent as to require essentially a new engine development program.

The above paragraphs describe the selection of the expansion ratio to attain the maximum possible thrust coefficient for one given set of conditions. This process is applicable to a single setting or fixed thrust engine. To select the expansion ratio of a throttleable engine involved the additional consideration of the minimum thrust condition. Referring still to figure B-2, the engine designed for Point "C" can be throttled down to a Point "D" before separation occurs. If the combination of thrust coefficient and chamber pressure at Point "D" yield a thrust value equal to or less than the minimum required, then the expansion ratio is adequate and the engine will be able to produce its maximum possible thrust at Point "C" as before. If, however, the thrust attainable at point "D" is not sufficiently low, a lower chamber pressure and/or thrust coefficient is needed. The only way that this can be accomplished without causing separation is to reduce the expansion ratio further and operate at Point "F". The maximum thrust that can be achieved with this nozzle corresponds to Point "E" which is in the under-expanded regime. Fortunately, the curves are very flat in the under-expanded region and the loss in thrust (difference between Point "C" and "E") may only be a few percent.

In this discussion, the criteria of separation has been considered to be a constant exit-to-ambient pressure ratio (values between Pe/Pa = .3 to .4 are commonly given in the literature). Recently published data indicate that the separation pressure ratio is actually a function of the nozzle Mach number, and hence changes with expansion ratio. This effect must be incorporated into the selection of the actual expansion ratio. With the operating characteristics of the LEM engines, separation may occur at pressure ratios as high as .45 to .80 as shown by the "Separation" curve in figure B-2. This is unfortunate and further compromises the design for atmospheric operation by increasing the minimum throttle settings to points "D_1" and "F_1" respectively.

From the previous paragraphs, it is apparent that the parameters which affect the selection of the expansion ratio are:

- Chamber pressure/ambient pressure (dictates thrust coefficient).
- Exit pressure/ambient pressure (separation criteria).
- Minimum thrust level required.

Hence, there are several possible approaches which have to be considered to determine the performance of the modified descent engine for use in the LTA-9. Ambient pressure could be either 14.7 psia for sea level (Langley) operation or 12.5 psia for operation at 4500 feet (WSMR). Maximum chamber pressure at this instant is 145 psia for the Rocketdyne engine and 110 psi for the parallel STL engine. The minimum thrust level required has yet to be established. If the vehicle is operated in a tethered mode, it will be desirable to reproduce the minimum thrust of the LEM, viz 1050 lbs. If free-flight operation is contemplated, this low thrust level does not have any real use and hence a higher minimum thrust may be acceptable. Figure B-3 shows that to simulate the same minimum mechanical power (a significant structural dynamics parameter) requires a minimum thrust of only 2000 pounds.

Table B-1 shows the performance trade-offs for a number of operating conditions. The attainable throttling range is shown vs. expansion ratio in figure B-4 to B-7 for several possible operating conditions. Figure B-8 shows the portion of the nozzle performance map applicable for this study. The performance data tabulated is based on the assumption that the nozzle will be modified to a 15 degree half-angle cone in order to eliminate the loss associated with the large divergence angle that will occur if the existing nozzle is simply "chopped off" at the appropriate expansion ratio. The nozzle separation pressure ratio was obtained by calculating the separation Mach number and using the data from the Arens/Spiegler paper in AIAA Journal - March 1963. For purposes of this study, the ratio of specific heats ($\gamma = 1.22$) is considered to be the same as for the LEM engine since it has been shown that with the present LEM propellants no recombination will take place beyond an expansion ratio of about 1.1; i.e., the flow is frozen.

A review of the tabulated performance parameters shows that for atmospheric operation at maximum throttle setting, only the thrust and specific impulse are reduced but the engine operating characteristics upstream of the throat are the same as in vacuum.

This includes the propellant valve settings, mass flow, chamber pressure and engine vibratory characteristics. Since these engine parameters are unchanged, the propulsion pressurization and propellant feed systems will behave exactly as in vacuum. Thus, if only maximum throttle operation is contemplated, the only modification required by the propulsion subsystem will be the reduction in expansion ratio.

However, as soon as the descent engine is throttled, which is a prime requirement for LTA-9 operation, all the engine operating parameters listed above will differ from their values in vacuum. To provide a given thrust value with the atmospheric engine requires a higher chamber pressure and larger fuel flow. This, in turn, affects the throttle position, valve settings and helium injection throttling program. Thus, although any thrust level within the engine performance range can be attained, the entire propulsion subsystem will possess different characteristics. Since the pressurization gas and propellant mass flow rates are not the same as in vacuum, the system transient characteristics will not be reproduced. Hence, atmospheric testing will not adequately upgrade the key phase of the descent propulsion system-throttling operation. Figure B-9 compares the throttling performance for LTA-9 with that of the LEM descent engine.

Since all control inputs to the propulsion subsystem are via electrical signals, the extent of the control modifications will be limited to a change in the throttle lever setting for manual operation and the output signal of the S and C thrust controller.

With regards to the modification of the descent engine mounting provisions, engine gimbal attachment points will have to be relocated since the present scheme requires an expansion ratio of about 6 to retain the existing support points. Figure B-10 shows the modified descent engine installation in LTA-9.

In view of the application of the subsystem; that is, repetitive atmospheric operation, it will be advantageous to substitute or eliminate certain components that do not affect the overall operation of the vehicle. In this category would fall such items as burst discs, squib valves and similar hardware. A review of the functions of these items indicates that in general the purpose of this equipment is to insure long duration isolation of various components of the pressurization and feed system. If it is desired to retain the functions of these items, it would be advantageous to substitute with solenoid or mechanical valves and avoid need of replacing those components after each run.

To summarize: The propulsion subsystem modifications required for atmospheric usage of the LTA-9 vehicle involve a reduction in the descent engine expansion ratio and a modification of the engine gimbal attachment points. For repetitive operation with a minimum of down-time, the one shot items such as squib valves and burst discs would either be eliminated or replaced with reusable hardware. Since the ascent stage will only be operated in an altitude facility in conjunction with the LTA-8 program, no modifications are required for the ascent propulsion subsystem with the possible exception of incorporating reusable hardware.

B.3 MODIFICATION OF RCS COMPONENTS

The modifications required by the reaction control subsystem components for LTA-8/9 program are similar to those required by the Propulsion Subsystem. In the LTA-8 vehicle, operating in an altitude facility, no modifications to the system are required. For repetitive use the squib valves and burst discs will be removed and reusable hardware will be substituted wherever required. For atmospheric use in the LTA-9 vehicle, the nozzle expansion ratio will be reduced to about 1.7:1. These modified nozzles are identical to the units that will be procured for the RCS development program. Another modification involves the pressure regulators used in the RCS pressurization systems. These regulators, unlike the units used in the propulsion subsystem, sense ambient pressure and hence will have to be readjusted for atmospheric operation. For atmospheric operation, RCS nozzle thrust will be reduced from a vacuum value of 100 pounds tO 57.5 pounds.

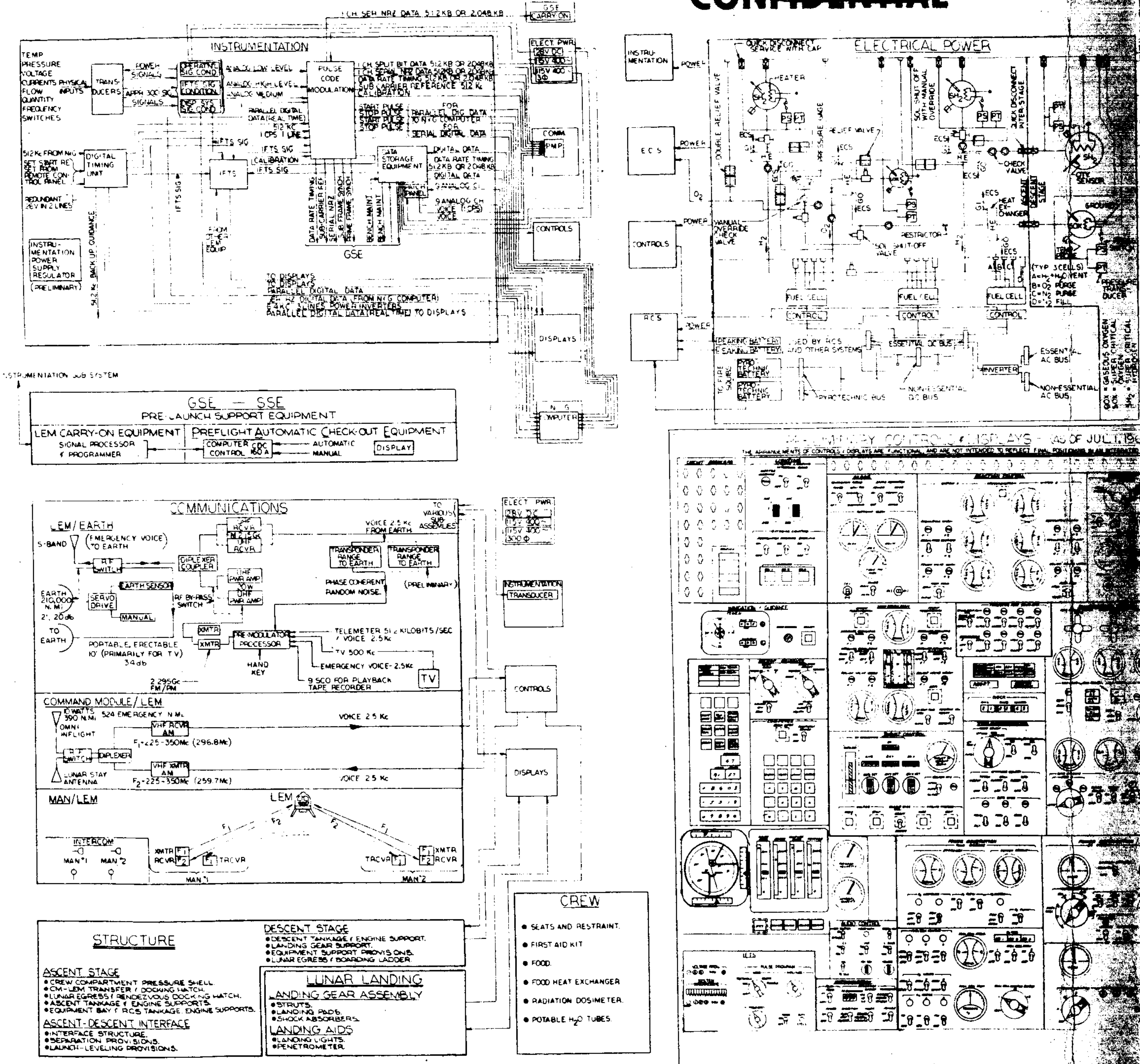
TABLE B-1

EFFECTS OF TRADE-OFFS FOR ATMOSPHERIC OPERATION

DESCENT ENGINE

VEHICLE	LEM		LTA-9 at S.L.				LTA-9 at 4500 FT.			
ENGINE GOAL	10:1 Range		Max. Thurst		Min. Thrust		Max. Thrust		Min. Thrust	
THROTTLE SETTING	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
Max. Pc = 145 psia										
Thrust	10500	1050	7050	2550	6760	1050	7250	2500	6930	1050
Isp	305	285	204	162	196	116	210	167	201	127
ε	53	53	2.0	2.0	1.2	1.2	2.2	2.2	1.3	1.3
P_c	745	14.5	145	66	145	37	145	63	145	34
P_a	0	0	14.7	14.7	14.7	14.7	12.5	12.5	12.5	12.5
$\dot{W}$	34.5	3.7	34.5	15.8	34.5	9.0	34.5	15.0	34.5	8.3
Max. Pc = 120 psia										
Thrust	10500	1050	6830	2600	6480	1050	7030	2800	6700	1050
Isp	305	285	198	158	188	123	204	165	194	125
ε	44	44	1.8	1.8	1.07	1.07	2.1	2.1	1.17	1.17
P_c	120	120	120	57	120	29.5	120	59	120	29
P_a	0	0	14.7	14.7	14.7	14.7	12.5	12.5	12.5	12.5
$\dot{W}$	34.5	3.7	34.5	16.5	34.5	8.5	34.5	17	34.5	8.4

~~CONFIDENTIAL~~



[redacted]

FOLD-OUT #1

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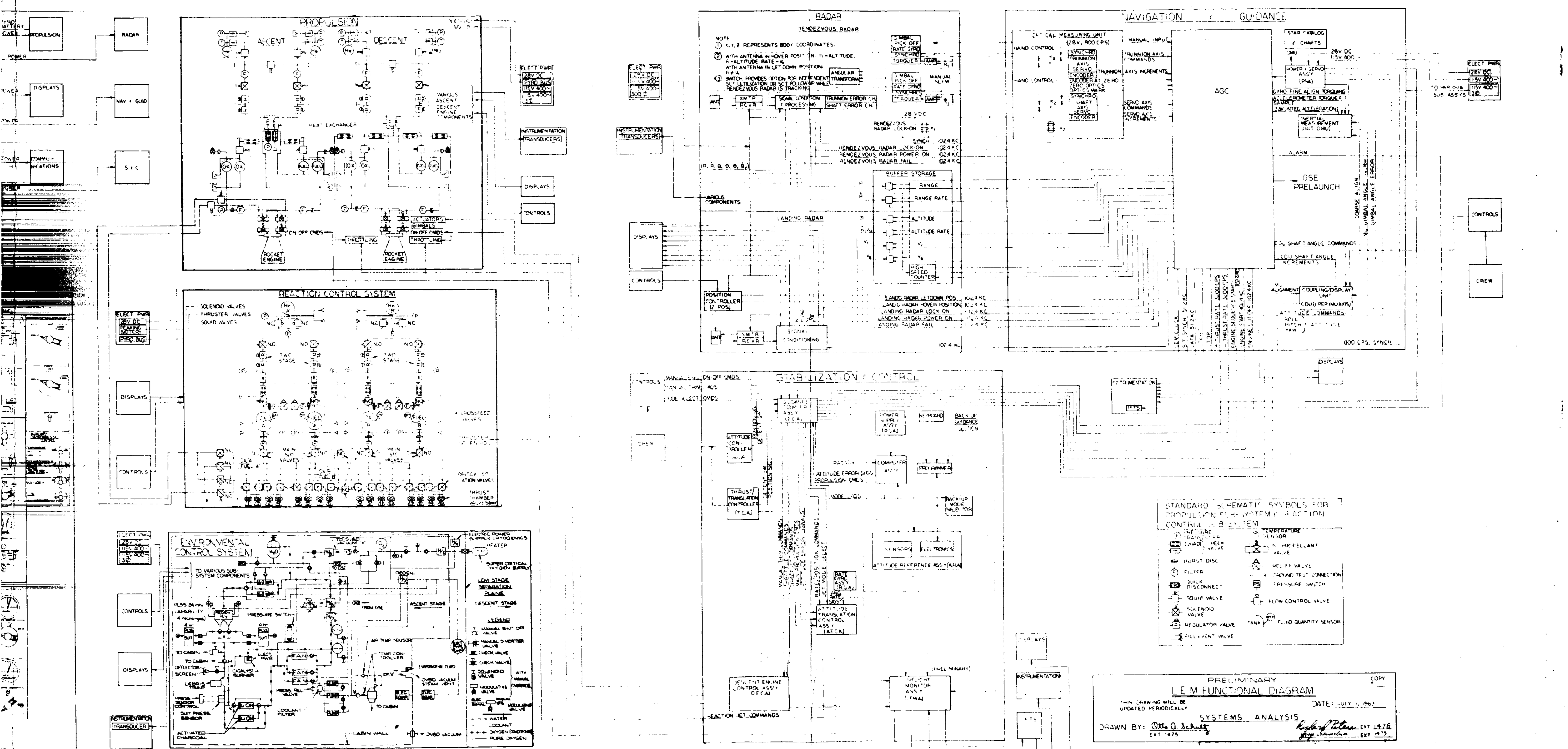

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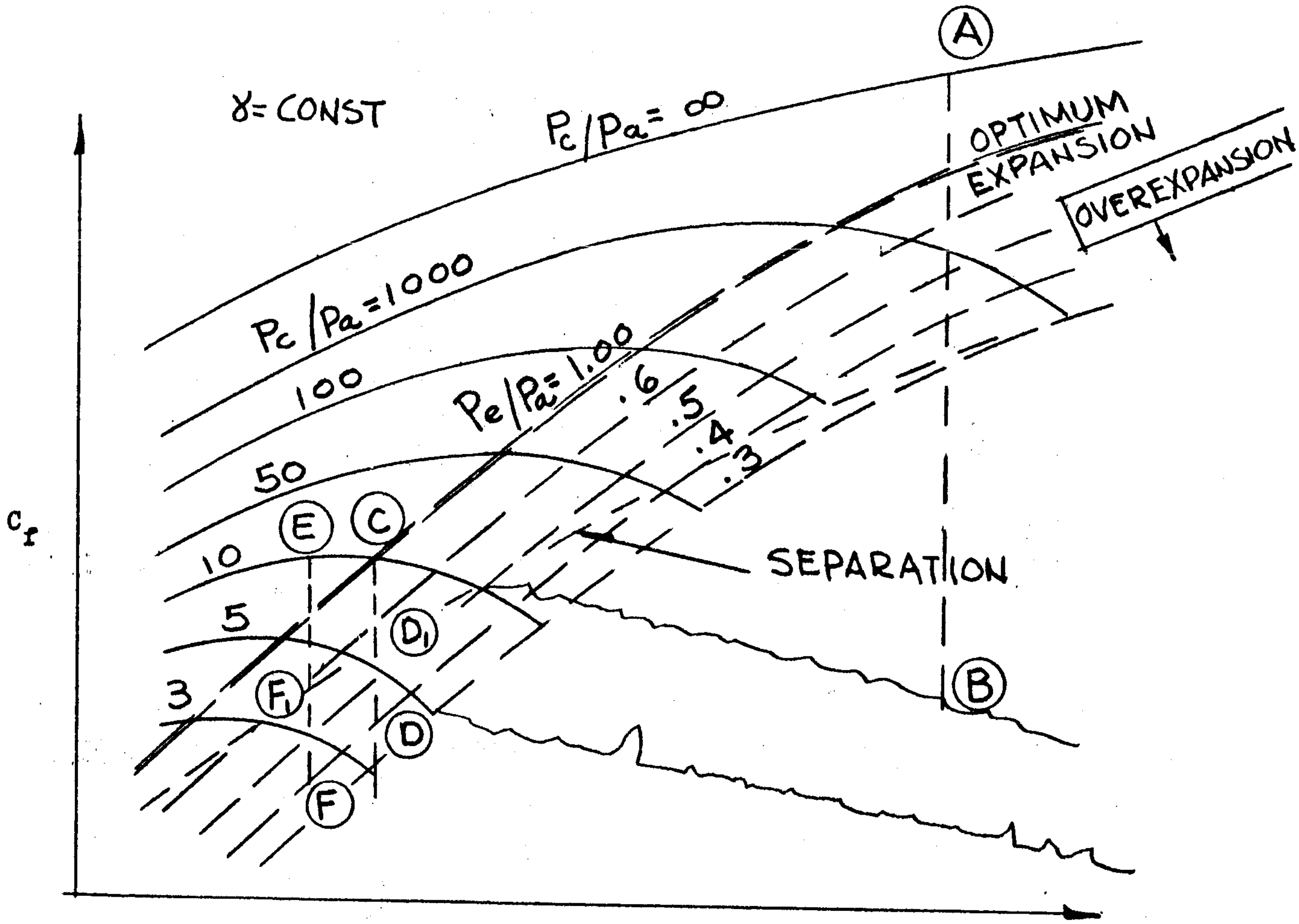
FOLD-OUT #2

Fig. B-1



$E = Ae/A_t$

Symbols: C_f = Thrust Coefficient = $T/P_c A_t$

A_t = Throat Area

Ae = Exit Area

E = Expansion Ratio = Ae/A_t

T = Thrust

Pa = Ambient Pressure

P_c = Chamber Pressure

P_e = Exit Pressure

= Ratio of Specific Heats

FIG. B-2

COMPARISON OF LEM AND LTA-9
ENGINE MECHANICAL POWER

$$\text{MECH PWR} = \frac{\varepsilon}{2} F g I_{sp}$$

ENGINE	P_a	ε
LEM	0	.53
LTA-9	12.5	.22

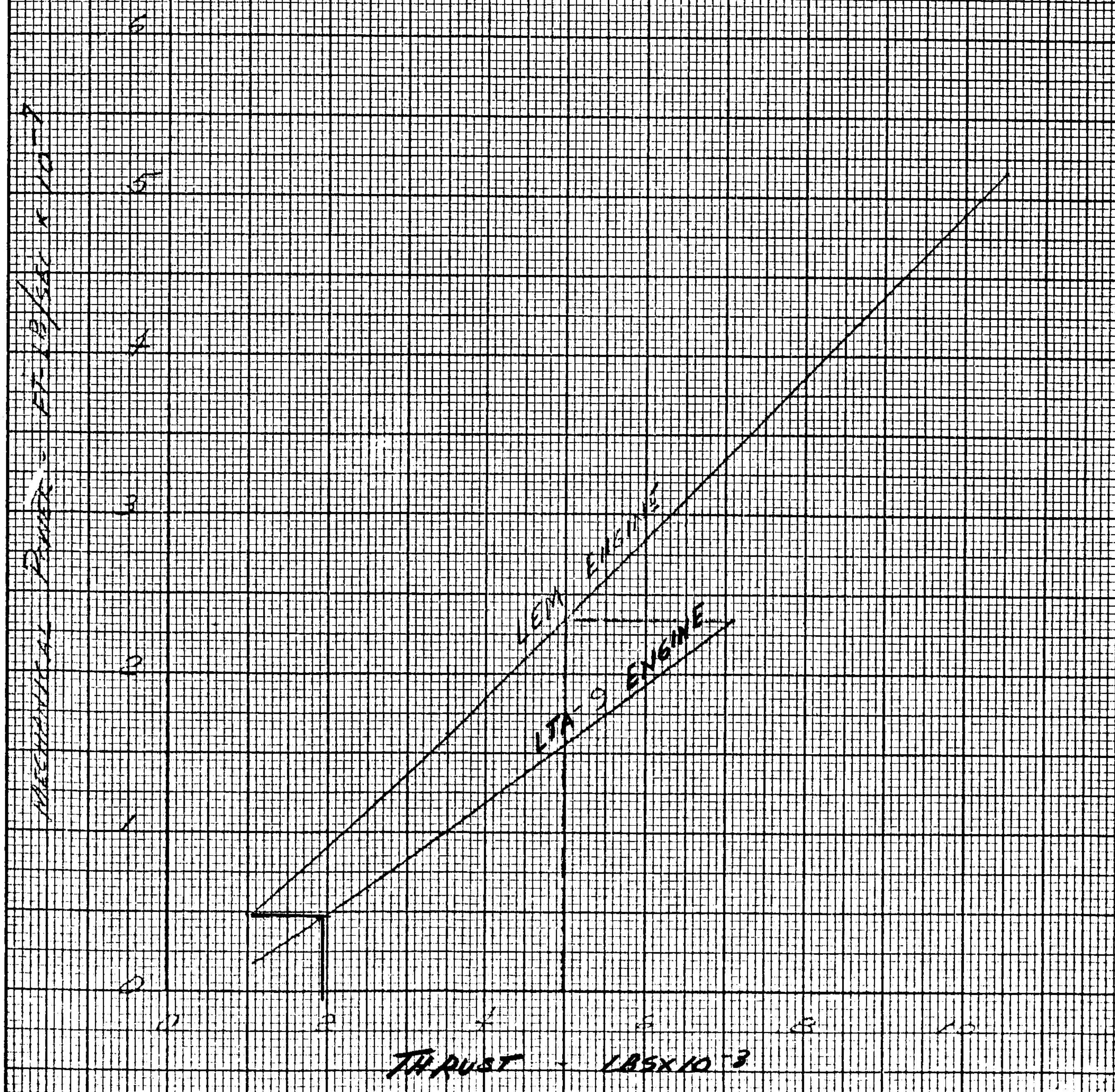
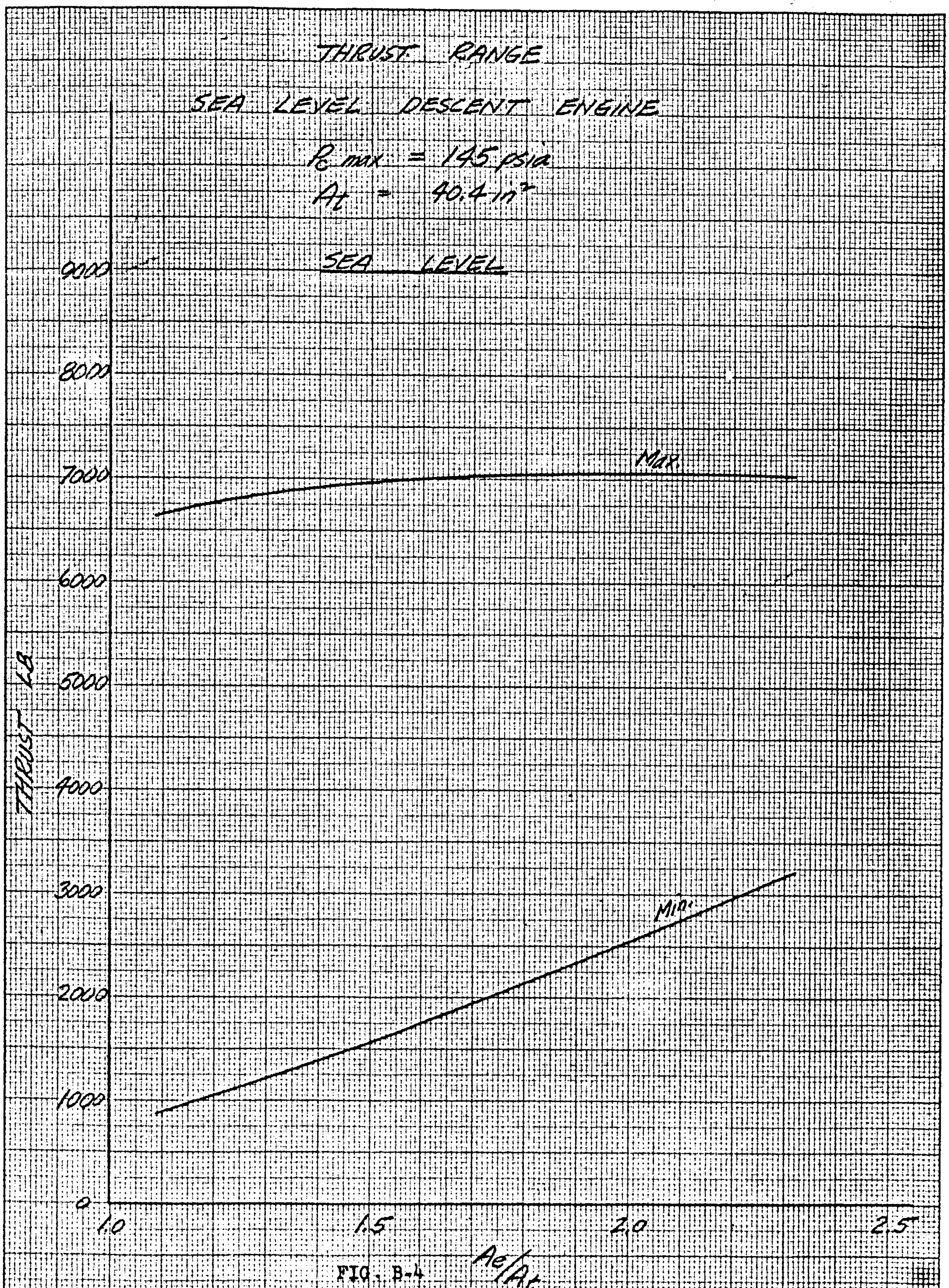


FIG. 3-3



THRUST RANGE
SEA LEVEL DESCENT ENGINE
P_c max = 145 psia
A_t = 40.4 in²
SEA LEVEL
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
THRUST LB
Max.
Min.
1.0
1.5
2.0
2.5
Ae/At

FIG. B-4

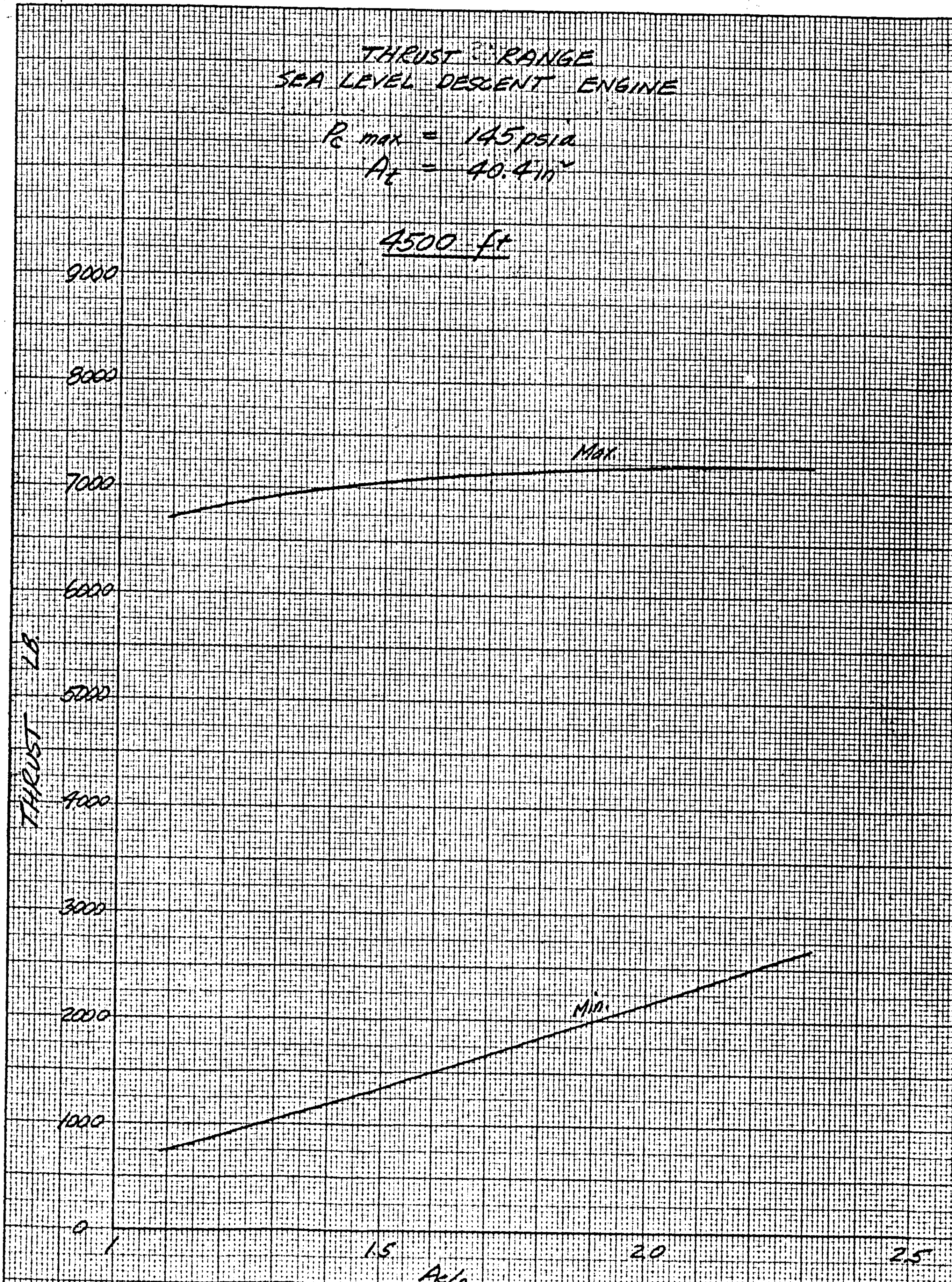

THRUST RANGE
SEA LEVEL DESCENT ENGINE
P_c max = 145 psia
A_t = 40.4 in²
4500 ft
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
THRUST LB
Max.
Min.
1
1.5
2.0
2.5
A_e/A_t

FIG. B-5

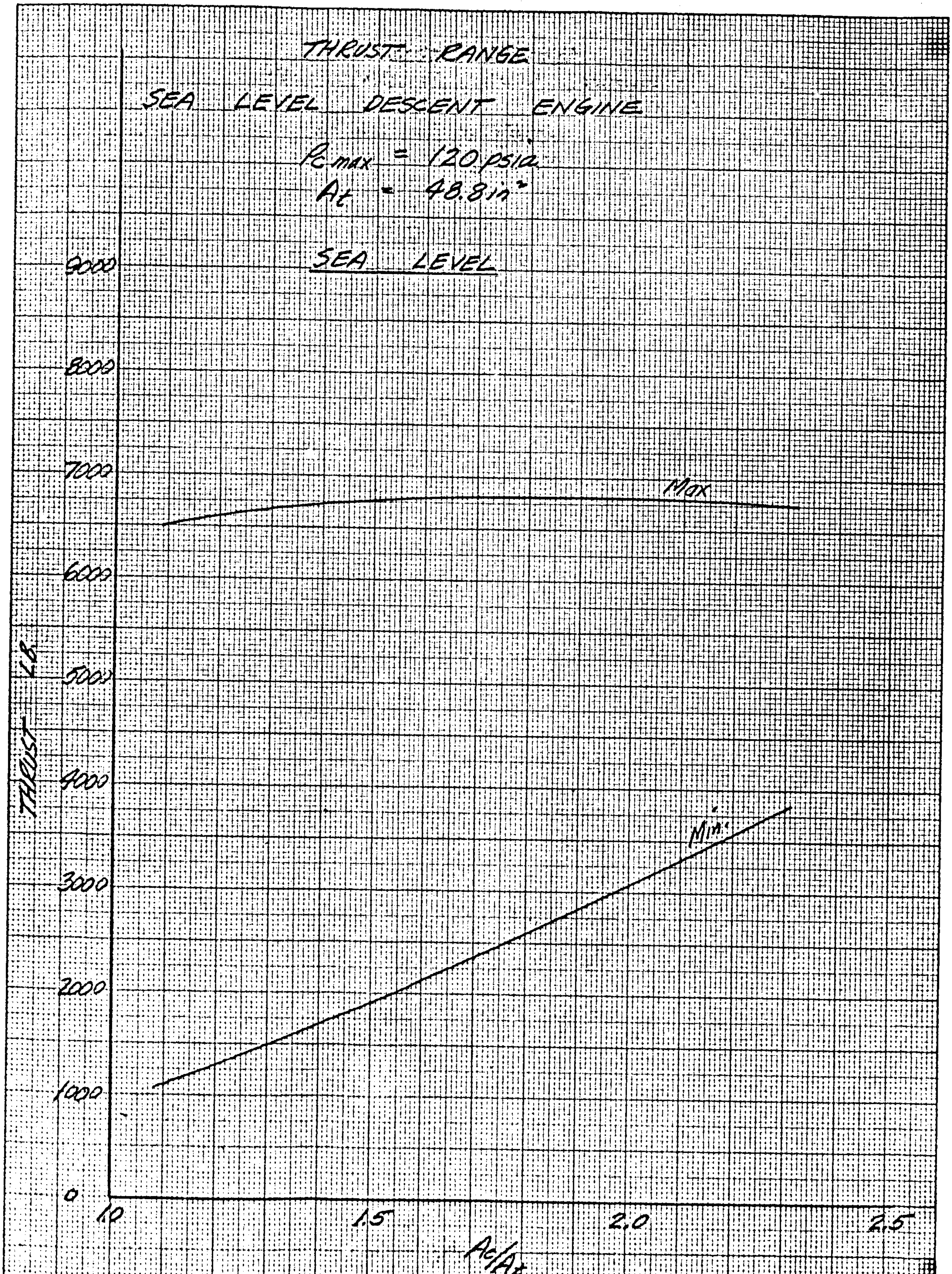

THRUST RANGE
SEA LEVEL DESCENT ENGINE
$P_{c\,max}$ = 120 psia
A_t = 48.8 in²
SEA LEVEL
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
THRUST LB
Max
Min
1.0
1.5
2.0
2.5
A_c/A_t

FIG. B-6

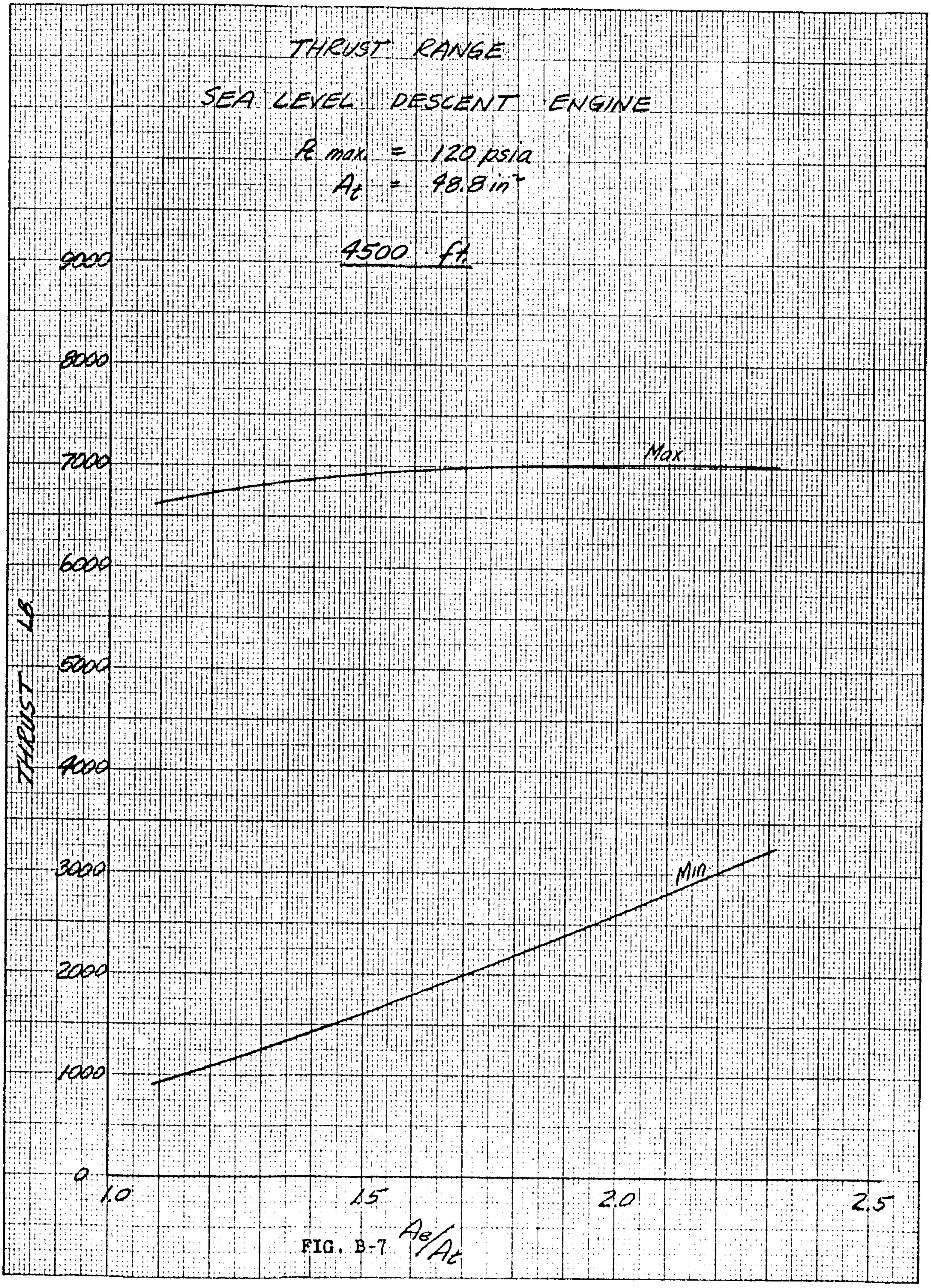
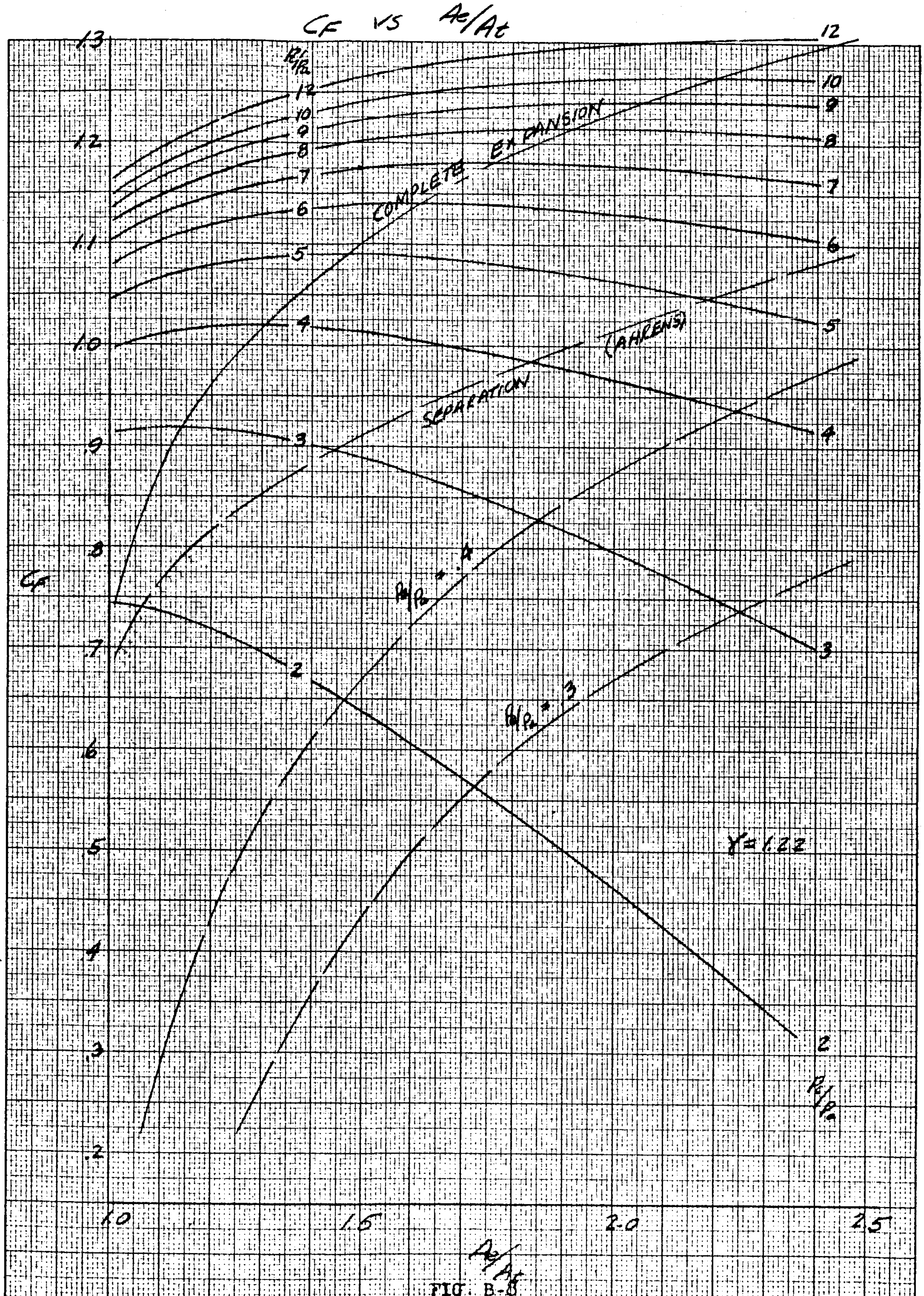

THRUST RANGE
SEA LEVEL DESCENT ENGINE
Pc max. = 120 psia
At = 48.8 in²
4500 ft.
Max.
Min
THRUST LB
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
1.0
1.5
2.0
2.5
Ae/At

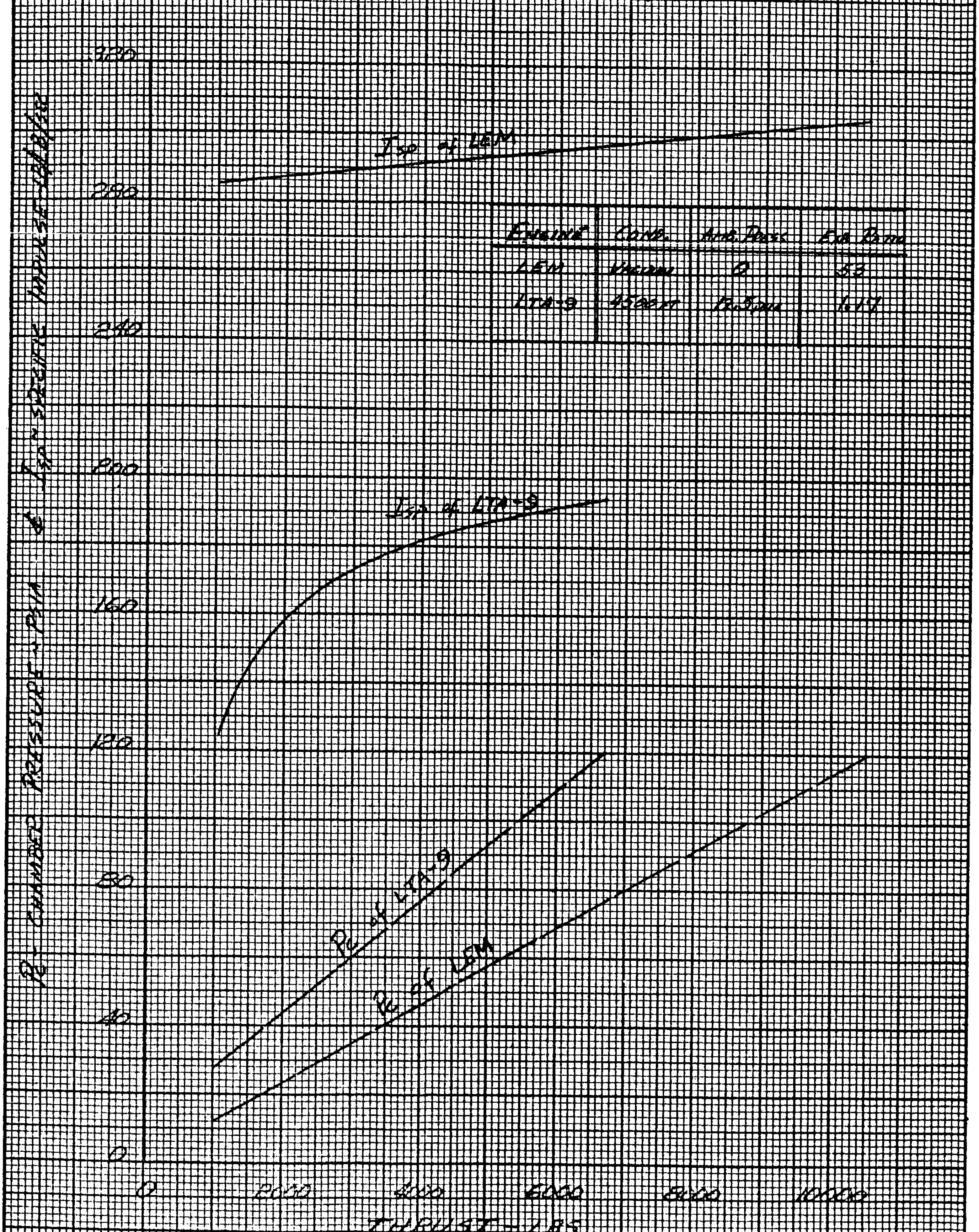
FIG. B-7



CF vs Ae/At
Pc/Pa
12
10
9
8
7
6
5
4
3
2
COMPLETE EXPANSION
SEPARATION (AHRENS)
Pe/Pa = .4
Pe/Pa = .3
γ = 1.22
CF
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
1.0
1.5
2.0
2.5
Ae/At

FIG. B-8

COMPARISON OF LTA-9 AND LEM DESCENT ENGINE PERFORMANCE



ENGINE	COND.	AMB. PRESS.	EX. RATIO
LEM	VACUUM	0	53
LTA-9	4500 FT	12.5 PSIA	1.17

FIG. B-9

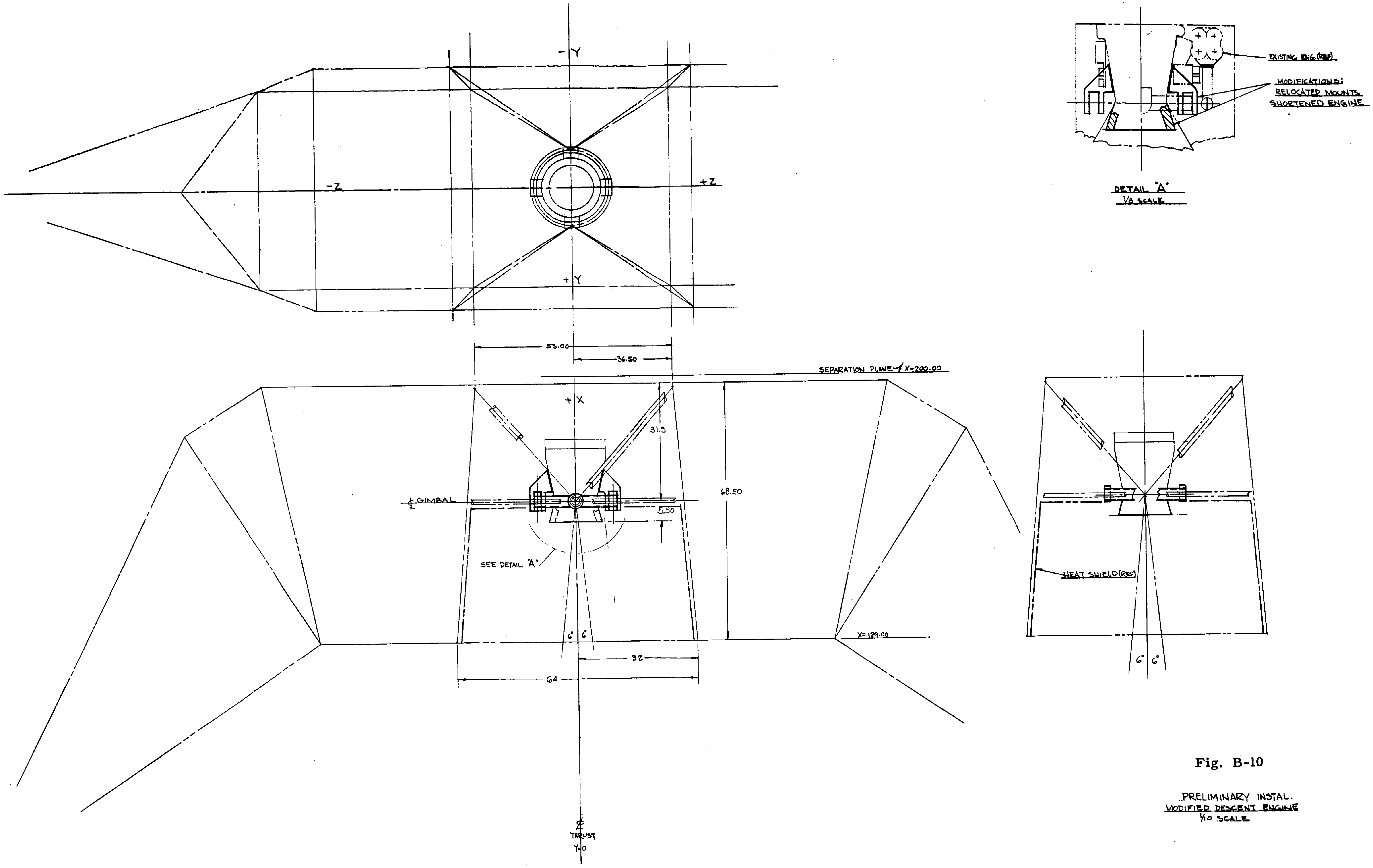


Fig. B-10

PRELIMINARY INSTAL.
MODIFIED DESCENT ENGINE
1/10 SCALE

APPENDIX C

TEST VEHICLE CONFIGURATION

C.1 CONFIGURATION DESCRIPTION

The vehicle design criterion for both LTA-8 and LTA-9 is minimum modification of the basic LEM spacecraft. Both are all-rocket powered and contain integrated and operable LEM subsystems. The subsystem modifications required for each vehicle have been described in Appendix B. These modifications are necessitated by the operational environment under which each vehicle accomplishes its respective objectives. The unmanned LTA-8 is tested under simulated LEM altitude conditions; and as such is virtually a complete LEM. LTA-9, the manned atmospheric flight vehicle employs integrated subsystem equipment with modifications brought about by a combination of operating in the earth environment, crew safety and the vehicle's dynamic test objectives.

C.1.1 LTA-8 Configuration

Structurally, the LTA-8 is a complete LEM spacecraft. However, installation of the vehicle in the test cell will necessitate removal of the LEM landing gear. No modification for attachment to the soft mounts on the test stand is required. This mounting interface is identical to that of the LEM spacecraft during acceptance test firings and that of LTA-5, the Propulsion Qualification test article. Attachment is made via the LEM-launch vehicle attachment points. The boost phase is the critical design condition for this hardware and no structural reinforcement is required for the LTA-8 descent or ascent firing loads.

Operating the vehicle in an altitude test stand at WSMR will result in the use of LEM Propulsion, Reaction Control, Electrical Power Supply and Environmental Control Subsystems without modification to either the subsystem components or their arrangement in the LEM. The electronic subsystems: Stabilization and Control, Navigation and Guidance, Instrumentation and Communications will be installed as on LEM. Although the test vehicle will be unmanned, Crew System equipment will be installed in a manner identical to the LEM vehicle.

Items that do not contribute to attaining the LTA-8 integrated system test objectives or affect the systems structural dynamics will be omitted. These items include:

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Food and Storage
Water(potable)
Chart Book and Catalog
Scientific Equipment
S-Band Lunar Stay
Erectable Antenna
Tape Recorder & Reels
Space Suits
Portable Life Support System
Radiation Dosimeters
Spare Parts

In the event a requirement develops for investigating the environmental response of any of the above equipment, they would be installed in the test vehicle. The test instrumentation aboard LTA-8 includes operational LEM PCM and R&D telemetry packages; as in the early space flight LEM's, the R&D telemetry equipment would be installed in place of the omitted (lunar) scientific equipment.

C.1.2 LTA-9 Configuration

The LTA-9 structural configuration is characterized by the addition of a gimbal structure to enable tethered flight operations, and modification to protect the vehicle under repeated descent engine firings and manned landing conditions. Again, reference is made to Appendix B for discussion of the LTA-9 modifications.

C.1.2.1 Gimbal Assembly

The gimbal assembly design shown in Figure C.1 is preliminary and, conceptually, is adaptable to either a helicopter-tether or a ground facility-tether. The gimbal structural design was predicated on manned aircraft safety margins and was designed for a 3 g limit loading with a 1.5 factor on limit load. In order to minimize the contribution of gimbal assembly inertia to rotational vehicle dynamics (especially about the yaw and roll axes for the gimbal design illustrated) attention was given to weight control, see sections C.2 and C.3.

The gimbal structural arrangement, patterned after the LRC LLRF configuration, consists of two dural tube, vertical side components with a yoke at the lower extremity picking up the gimbal-vehicle interface structure. The upper end is pinned to the overhead "I" beam structure, which in turn is bolted to a small tubular beam connected by cables to the cable drum on the overhead follower.

The interface between the gimbal structure and the vehicle hard points must accomodate rotation about the LEM Y and Z axes, LEM pitch and yaw respectively. LEM roll, motion about the X axis, is accomodated through a swivel connection at the upper end of the gimbal assembly.

In order to minimize extraneous moments induced with changes in pitch attitude, the interface mechanism provides for maintaining the pitch axis pivot point on the vehicle's vertical c.g. position. Two electrically controlled and actuated screw jacks program and position the pivots as a function of propellant consumption to meet this requirement. The net effect is a gradual lowering of the vehicle with respect to the gimbal structure to maintain alignment of the vertical c.g. with the pitch gimbal axis throughout the flight.

Z axis gimballing is accomplished by pivoting the overhead beam of the assembly yoke about its own c.g. with resultant parallelogram motion of the vertical side members. Electrically actuated weights are installed on the overhead beam (parallel to the Y axis) and are primarily pre-flight lateral trim devices. An alternate lateral trim method would involve off-set of the pivot point on the overhead beam.

The preliminary gimbal assembly design described here, and the results of the stress analysis of the gimbal structure, fittings and electrical screw jack are on file at Grumman. Design and analysis of the gimbal system will be accomplished during the LTA-9 detailed design period.

C.1.2.2 Vehicle Arrangement

The LTA-9 subsystem installation will be as similar to that of the LEM as manned atmospheric operations will permit. To reduce operational hazards the LEM fuel cells will be replaced with a battery power supply; however, the electrical power distribution system will remain the same. Since the S-band lunar communication equipment and the scientific equipment do not contribute to the primary test objectives of LTA-9, i.e., atmospheric dynamic flight operational testing with man in-the-loop, these items will be omitted. The substitution of a dummy ascent engine has been discussed in a previous appendix as were the major modifications to the operable LEM descent engine and reaction control engines. The flight control and navigation and guidance equipment in conjunction with the descent propulsion and crew system equipment are of highest importance for the LTA-9 tests. The modified LEM ECS equipment cooling section will be relied upon to maintain the on-board LEM subsystems within LEM equipment operating temperature limits. To insure against inflow of toxic exhaust products the ECS subsystem will maintain a slight positive cabin pressure. The non-essentials listed in Section C.1.1 will also be omitted from LTA-9 with the exception of space suits. It is anticipated that manned operational experience would include flight operations with the crew in suits. Additional modifications for atmospheric operations include removal of the descent engine skirt and the addition of thermal protection in the descent stage engine well as discussed in Appendix B.

C.2 MASS PROPERTIES SUMMARY

LTA-8 and LTA-9 weight balance and inertial characteristics were derived from the mass properties of the LEM as of 15 June 1963. Detailed derivations of the weights and balance for the test configurations have been made and are on file; for conciseness these analyses are summarized for presentation below.

The approach used for LTA-8, the restrained firing integrated system test article, is based on a complete LEM, with the few deletions noted in Section C.1.1. The mass properties of LTA-8 are compared to the LEM in Table C-1. The hover and touchdown weights of the two are similar since both reflect full propellant loadings as well as similar equipment arrangements.

Proper investigation of LTA-9's capabilities in fulfilling flight dynamic test objectives requires realistic weight, balance and inertia data. The LEM target weight itemization of 15 June 1963 was used in the development of mass characteristics for the modified subsystem equipment for LTA-9. The resulting mass properties of the tethered flight LTA-9 configuration are compared to the LEM in Table C-1, for LEM hover and touchdown conditions. The differences in weight, c.g. and inertias between LTA-9 and LEM for corresponding points in the terminal descent phase of the lunar landing mission are small. The comparison is made for LTA-9 with and without inert ascent propellant and includes the weight of descent propellant for a nominal two minute terminal descent. Appropriate gimbal inertias are included.

TABLE C-1

COMPARISON OF MASS PROPERTIES

		Mission Phase	Weight (Lbs.)	Arm (In.) X	Arm (In.) Y	Arm (In.) Z	Inertia (Slug Ft^2) I_X	Inertia (Slug Ft^2) I_Y	Inertia (Slug Ft^2) I_Z
LEM	(For LTA-9 comparison)	Hover	12398.9	213.1	-0.3	-1.1	8508	10289	11299
		Touchdown	11408.7	219.4	-0.4	-1.2	7823	8261	9759
	(For LTA-8 comparison)	Separation	25493.2	188.2	-0.2	-0.5	17499	19466	18629
LTA-9 Tethered	No Ascent Prop.	Hover	7500	204.3	-1.7	-2.4	5957	6016	8167
		Touchdown	6444	196.0	-1.4	-2.0	6657	7150	9835
	Full Inert Asc. Prop.	Hover	11767	211.1	-0.9	-1.5	8927	9675	13373
		Touchdown	10292	220.0	-1.0	-1.3	7968	7556	11121
LTA-8 Restrained		Separation*	23891	187.8	-0.2	-1.5	15401	16928	16084

* Crew and Crew expendables offloaded.

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C.3 COMPARISON OF LTA-9 HANDLING CHARACTERISTICS

The handling characteristics of the tethered LTA-9 are to a large extent dependent upon the descent engine, RCS and stabilization and control subsystem modifications described in Appendix B. However, the response of the vehicle is also influenced by propellant weight-run time requirements and the design of the gimbal assembly.

The nominal terminal descent mission time is on the order of two minutes. The LEM inertial properties for the terminal descent were summarized in Table C-1. Figure C-2 compares descent engine running time and LTA-9 gross weight for full and zero inert ascent propellant loadings. The figure can also be interpreted as an indication of the potential for altering vehicle inertias and thereby vehicle handling characteristics through the selection of various combinations of inert ascent propellant, ballast and descent propellant weight.

Detail gimbal assembly design should minimize the inertial contribution of the gimbal structure particularly about the yaw and roll axes. While gimbal weight itself is not a major consideration, the vehicle reaction control must overcome the gimbal assembly inertia for yaw and roll maneuvering. Analysis of the preliminary gimbal assembly design shows that it could contribute on the order of 10% to the LTA-9 vehicle inertias. Gimbal friction is another source of degraded response and the detail design of any gimbal mechanism would also emphasis minimal friction.

A comparison of the handling characteristics of the LEM and a tethered LTA-9 in terms of vehicle angular acceleration capability is presented in Table C-2. The vehicles are compared in the hover and touchdown points of the terminal descent. The LTA-9 vehicle reaction control rocket thrust is 57.5 lbs compared to 100 lbs thrust developed in space flight. The LTA-9 inertias are shown in Table C-1 and include the addition of a term for gimbal inertia around the LEM yaw and roll axes. The LTA-9 vehicle exhibits reduced angular control capability about all axes. However, the table indicates that by off loading the ascent propellant the differences between respective LEM and LTA-9 responses are reduced.

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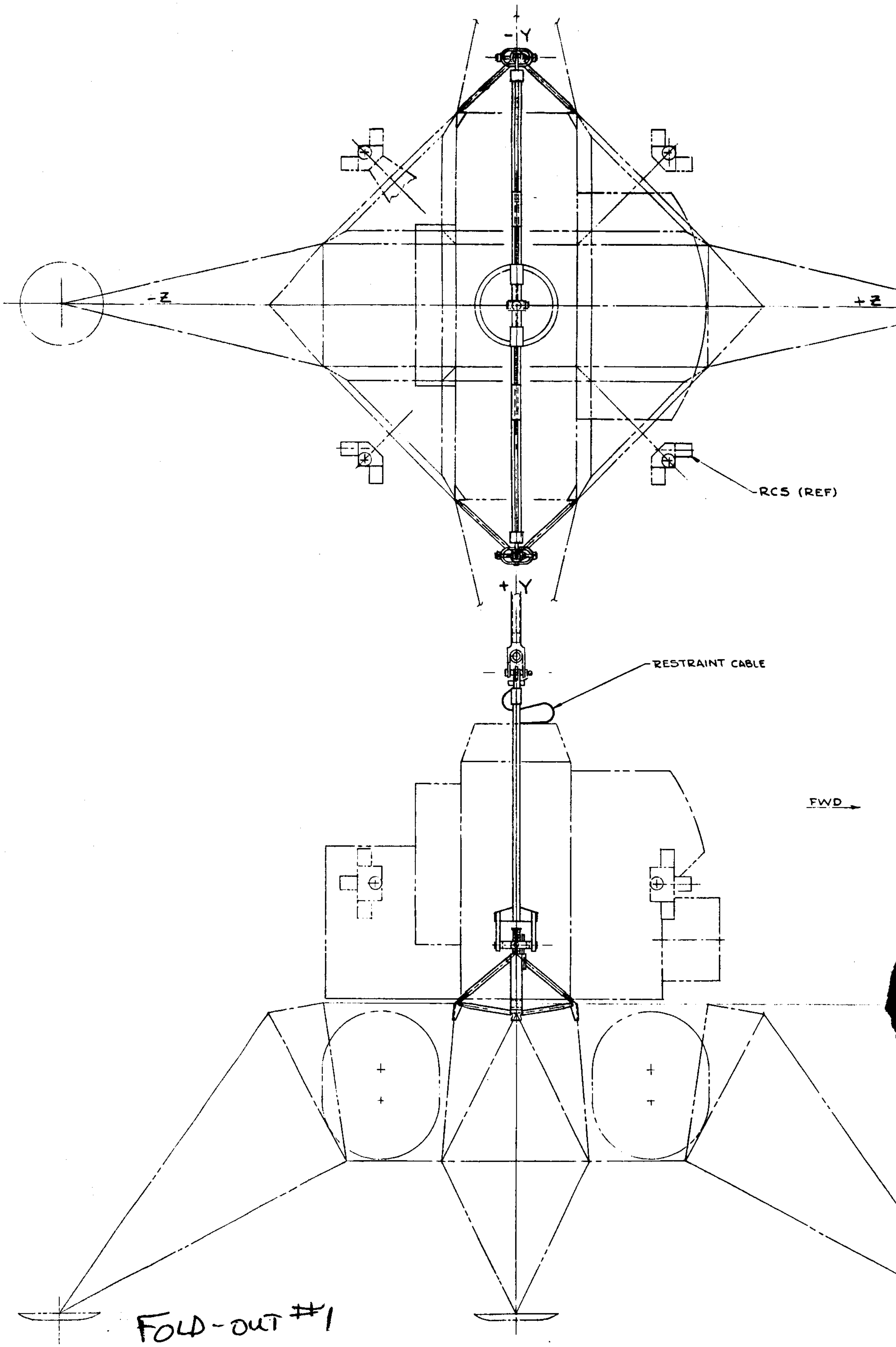
TABLE C-2

HANDLING PROPERTIES

Vehicle	Phase	α_X (°/sec^2)	α_Y (°/sec^2)	α_Z (°/sec^2)
LEM	Hover	6.87	6.07	5.56
	Touchdown	7.50	7.27	6.42
LTA-9 Tethered	Hover With Ascent Prop.	3.78	3.72	2.69
	Touchdown With Ascent Prop.	4.24	4.81	3.27
LTA-9 Tethered	Hover Without Descent Prop.	5.07	5.04	4.41
	Touchdown Without Descent Prop.	5.67	6.01	3.67

			X	Y	Z
Percentage Difference of Angular Control Capabilities of the LTA-9 with respect to LEM	Hover	With Ascent Prop	-45	-39	-52
		Without Ascent Prop	-26	-17	-21
	Touchdown	With Ascent Prop	-42	-20	-49
		Without Ascent Prop	-24	-21	-43

In this preliminary design no attempt was made to compensate for the reduced control capability by increasing the moment arm of the reaction control rockets, since the basic criterion was that of minimum modification to the LEM configuration. However, this method of increasing the LTA-9 control capability is feasible and will be investigated during the LTA-9 detail design phase.



FOLD-OUT #1

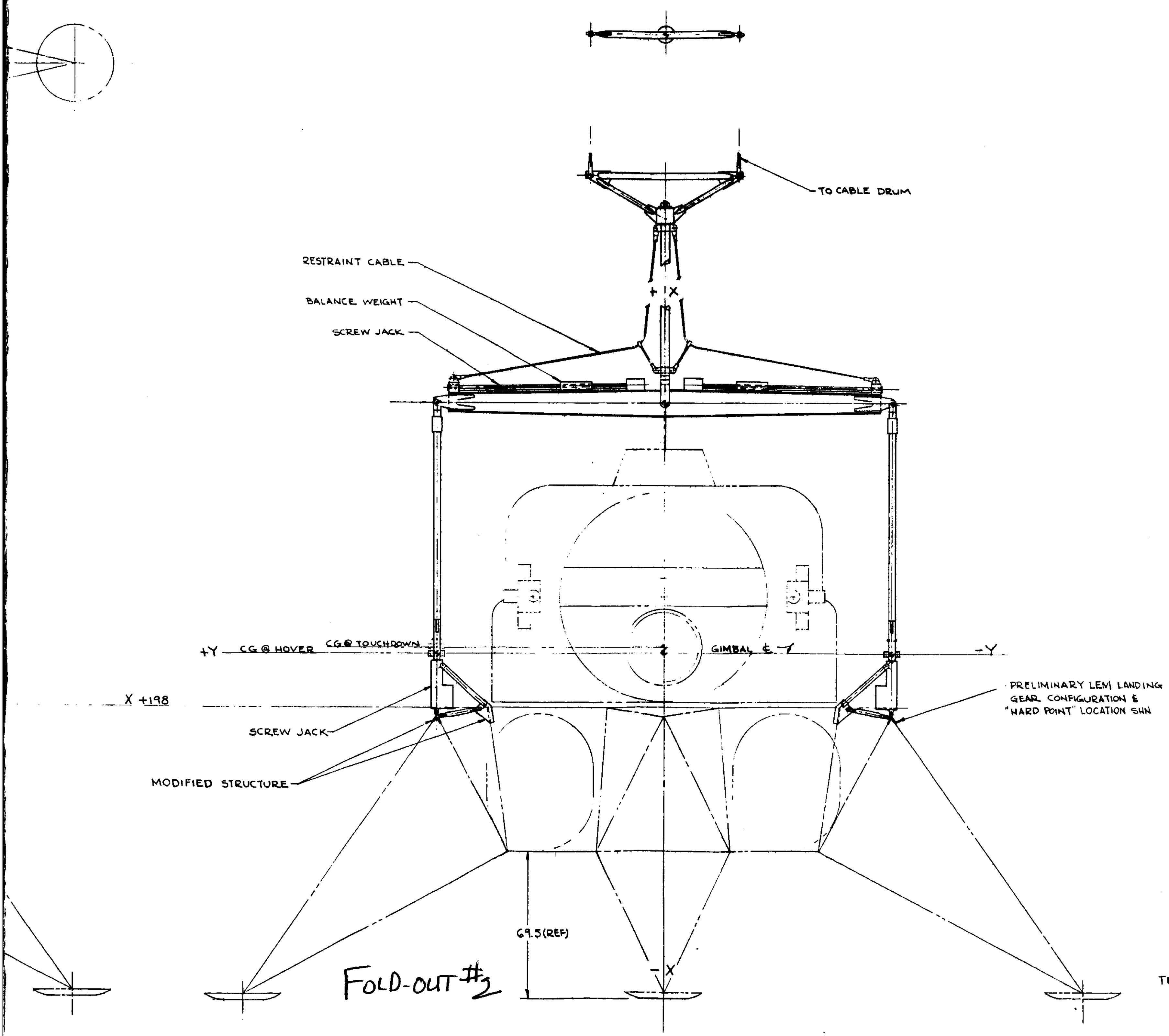


Fig. C-1

PRELIMINARY
LTA-9
TETHERED CONFIGURATION

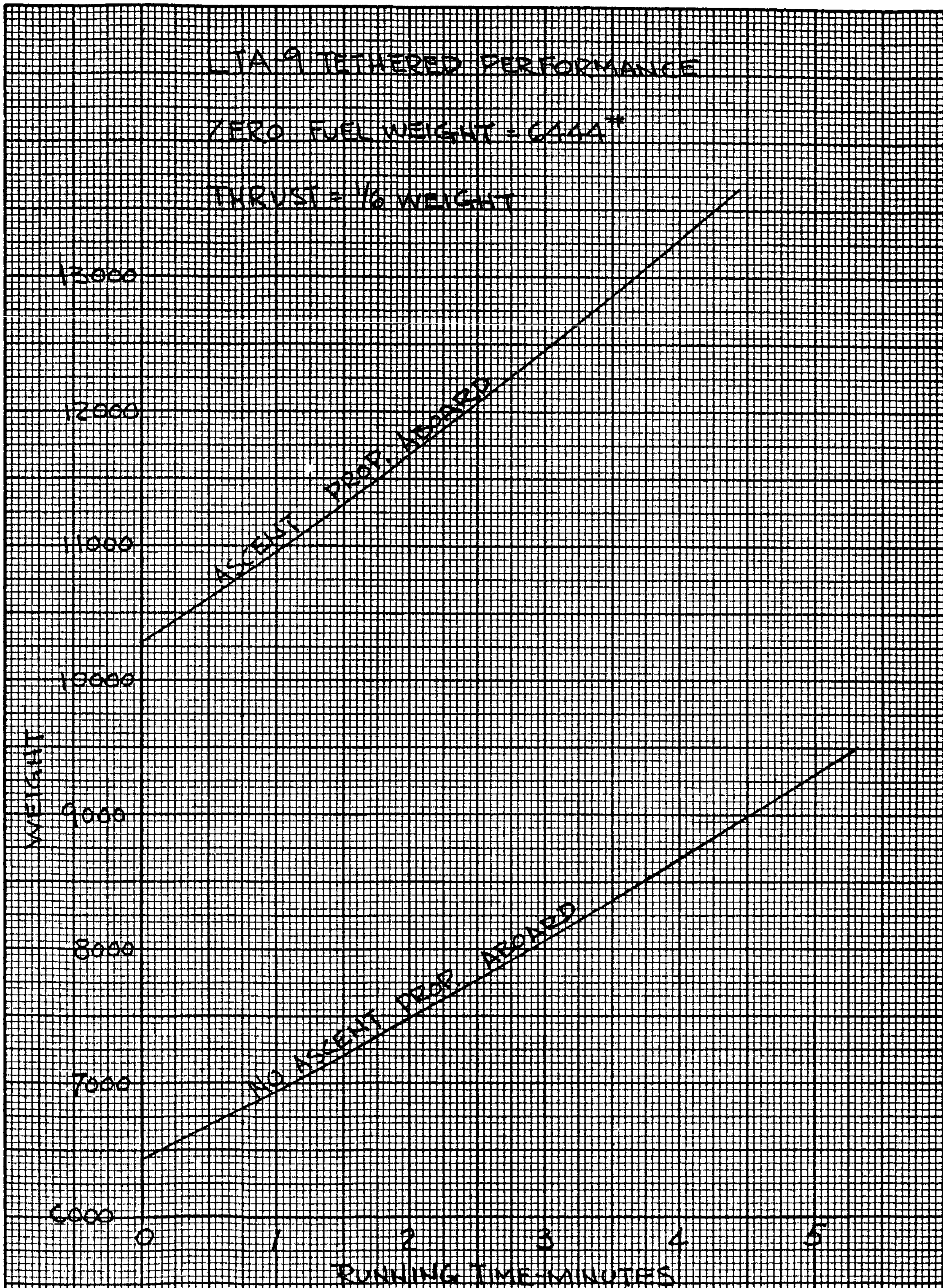

LTA-9 TETHERED PERFORMANCE
ZERO FUEL WEIGHT = 6444#
THRUST = 1/6 WEIGHT
13000
12000
11000
10000
9000
8000
7000
6000
WEIGHT
ASCENT PROP. ABOARD
NO ASCENT PROP. ABOARD
0
1
2
3
4
5
RUNNING TIME-MINUTES

FIG. 6-2

APPENDIX D-1

INTERACTION OF TETHERING RIG DYNAMICS WITH THE LTA-9 MOTIONS

As a method to simulate the lunar gravitational environment for the LTA-9 test program, vertical suspension of the LTA-9 with a cable adjusted to a tension equal to 5/6 of the LTA-9 has been investigated. In order to maintain the cable vertical, the cable is fixed to a tethering vehicle which is commanded to follow the motions of the LTA-9. Use of either a hovering helicopter or a carriage moving horizontally on a stationary elevated track has been investigated as the tethering vehicle. Six degrees of freedom is possible by mounting the LTA-9 in a gimbal fixture which is suspended at the lower end of the cable.

Interaction of the tethering rig dynamics with the LTA-9 motions is expected due to two effects, (1) the pendulum motion of the cable suspended LTA-9 and (2) the bending motion of the cable itself. These two effects will act to prevent the verticality of the suspending cable thereby imparting horizontal forces on the LTA-9 equal to the product of the cable tension and the cable off-vertical angle. In the analysis of the appendix, the pendulum and cable bending effects will be handled as decoupled to determine the separate cable reactive forces of each effect imparted to the LTA-9.

To maintain the cable vertical against pendulum effects, closed loop control is required where the off-verticality of the cable at the LTA-9 is nulled by commanded motion of the tethering vehicle. The off-verticality of the cable due to the bending of the cable will also be nulled by the pendulum closed loop control system. However, in stabilization of the closed loop pendulum control system, selection of control system gain and compensation were made with the objective of minimizing cable reactive forces on the LTA-9 where cable bending effects are considered only insofar as the control system bandwidth was designed to fall below the resonant frequency of the cable fundamental bending mode. For a more complete design analysis of the pendulum control system, use of an analog computer is required to simulate the coupling of the pendulum and cable motions together as they interact with the control motions of the LTA-9.

Also of importance are the coupling effects of the fuel slosh frequencies and the RCS (Reaction Control System) limit cycle frequencies with the cable bending and pendulum modes. Uncoupled fuel slosh frequencies in the descent tanks are estimated to be about 0.70 c.p.s. For instance, 1440 lbs of propellant, equivalent to 2 minutes of vehicle tethered operation, will slosh at 0.725 c.p.s. As the tanks empty a slight decrease in slosh frequency is expected. At the low tank levels, baffling placed in the bottom of the tanks to prevent deporting, will also act to subside the sloshing oscillations such that sloshing forces are reduced. Uncoupled RCS limit cycling frequencies are low. For example, for the LEM at the hover weight, RCS limit cycle frequencies of 0.167 c.p.s. are expected, increasing to 0.25 c.p.s. at the touchdown weight. It is expected that the use of the LEM

RCS on LTA-9 will exhibit similar limit cycle frequencies. A more complete analog computer analysis will include the effects of the RCS limit cycle and fuel slosh frequencies since they do fall close to the range of pendulum control system bandwidth and cable bending frequencies.

Before presentation of the analysis of this appendix, it is of interest to review preliminary results of the analog investigation of the coupled pendulum-cable bending dynamics on a tethered vehicle as performed for LLRF stationary rig at Langley Field, Virginia. This analysis considers a suspended vehicle weight of 10,000 lbs., a carriage weight of 20,000 lbs., and cable lengths of 50 and 200 ft. with a double cable weight of 2.4 lbs/ft. and tension of 8333.3 lbs. For the carriage control system, the carriage acceleration for input cable angle inputs is of the following form:

$$\ddot{x}_c = \left[K_{\dot{\theta}}\theta + K_{\theta}(\theta + .026h + .064\delta) + K_{\int\theta}\int(\theta + .026h + .064\delta)\,dt + K_{\ddot{\theta}}\frac{1}{(s/10 + 1)} \right] \left[\frac{1}{(s/10)^2 + \frac{2(.7)}{10}s + 1} \right]$$

where

θ = pendulum angle, deg.
h = bending angle of 1st cable bending mode, deg.
δ = bending angle of 2nd cable bending mode, deg.

The gains selected for the 50 and 200 ft. cables were:

	50 ft.	200 ft.
$K_{\dot{\theta}}$ $\frac{ft/sec^2}{deg/sec.}$	15.0	15.0
K_{θ} $\frac{ft/sec^2}{deg.}$	8.0	8.0
$K_{\int\theta}$ $\frac{ft/sec^2}{deg-sec.}$	2.00	0.50
$K_{\ddot{\theta}}$ $\frac{ft/sec^2}{deg/sec.^2}$	.40	1.60

For the carriage control system presented above, the analog runs of the cable angles, θ, δ, h, presented for an 11 ft/sec^2 horizontal step input into the suspended vehicle at the 200 ft/cable length, and a 8 ft/sec^2 input for the 50 ft. cable length, were used to calculate the horizontal reactive cable forces due to θ and h. Results are presented in figures D-1 and D-2. Additional data indicated the half wave length of the first cable bending mode of 50 ft. length as 107 ft., and for the 200 ft. cable length, as 208 ft. For the second cable bending mode, a half wave length of 49 ft. is indicated for the 50 ft. cable and 200 ft. for the 200 ft. cable.

The increase of the 50 ft. cable wave length of the first bending mode reflects the effect of the six foot gimbal wiffletree, from which the vehicle is suspended, on the half wave length of the first bending mode. First bending mode oscillation frequencies are indicated to be 1.0 c.p.s. for the 200 ft. cable length and 1.87 c.p.s. for the 50 ft. cable length as measured from Figures D-1 and D-2.

Figures D-1 and D-2 were modified for the LTA-9 vehicle with a representative initial weight of 12,000 lbs., a cable tension of 10,000 lbs., and a step acceleration of 2.68 ft/sec^2. (This acceleration occurs as a consequence of a 30 degree pitch angle and a thrust of 2000 pounds.)

The cable reactive forces resulting from the closed loop pendulum control were calculated and shown in Figure D-3. Using the block diagram developed in Section D-2 of this appendix the following transfer functions were obtained for the cable reactive force, on the LTA-9, $F_{R\upsilon}$, per horizontal force input, F_{jh}. (LLRF displacement, rate, and integral gains tabulated above, were used for the carriage acceleration at the two cable lengths.)

$$\underline{\ell = 200'} \qquad \frac{F_{R\upsilon}}{F_{jh}} = \frac{.134\,(s)}{(S + .0669)(S + .589)(S + 3.641)}$$

$$\underline{\ell = 50'} \qquad \frac{F_{R\upsilon}}{F_{jh}} = \frac{.536(S)}{(S + 16.59)(S + .296 \pm j\ .225)}$$

For a horizontal step input of 2.68 ft/sec^2, or a force of 1000 lbs., into the LTA-9, transient responses for the cable reactive force $F_{R\upsilon}$, were obtained at the two cable lengths and shown in figure D-3 for comparison to the transients obtained with the LLRF analysis as modified for the LTA-9 weight.

As indicated in figure D-3, the LLRF analog transients are not exactly matched since the analysis of this appendix did not include the coupling of the cable bending dynamics and the gimbal dynamics on the LTA-9 pendular motions. However, peak transient forces are similar enough to justify the comparison.

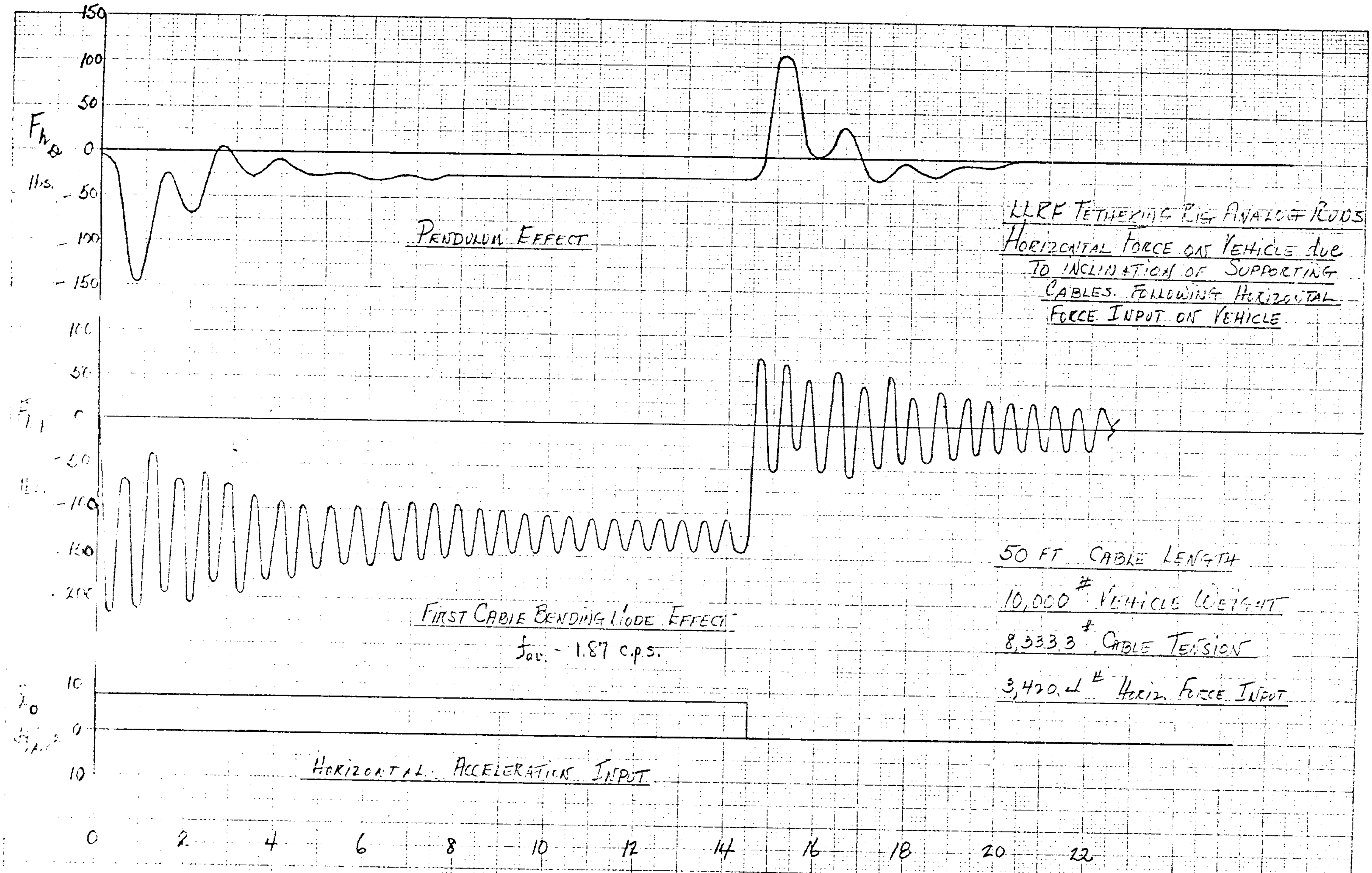

LLRF Tethering Rig Analog Runs
Horizontal Force on Vehicle due to Inclination of Supporting Cables Following Horizontal Force Input on Vehicle
Pendulum Effect
First Cable Bending Mode Effect
$f_{av.}$ - 1.87 c.p.s.
50 FT Cable Length
10,000 # Vehicle Weight
8,333.3 # Cable Tension
3,420.1 # Horiz. Force Input
Horizontal Acceleration Input
150
100
50
0
- 50
- 100
- 150
lbs.
F_{h_θ}
0
2
4
6
8
10
12
14
16
18
20
22
Time - seconds

Figure D-1

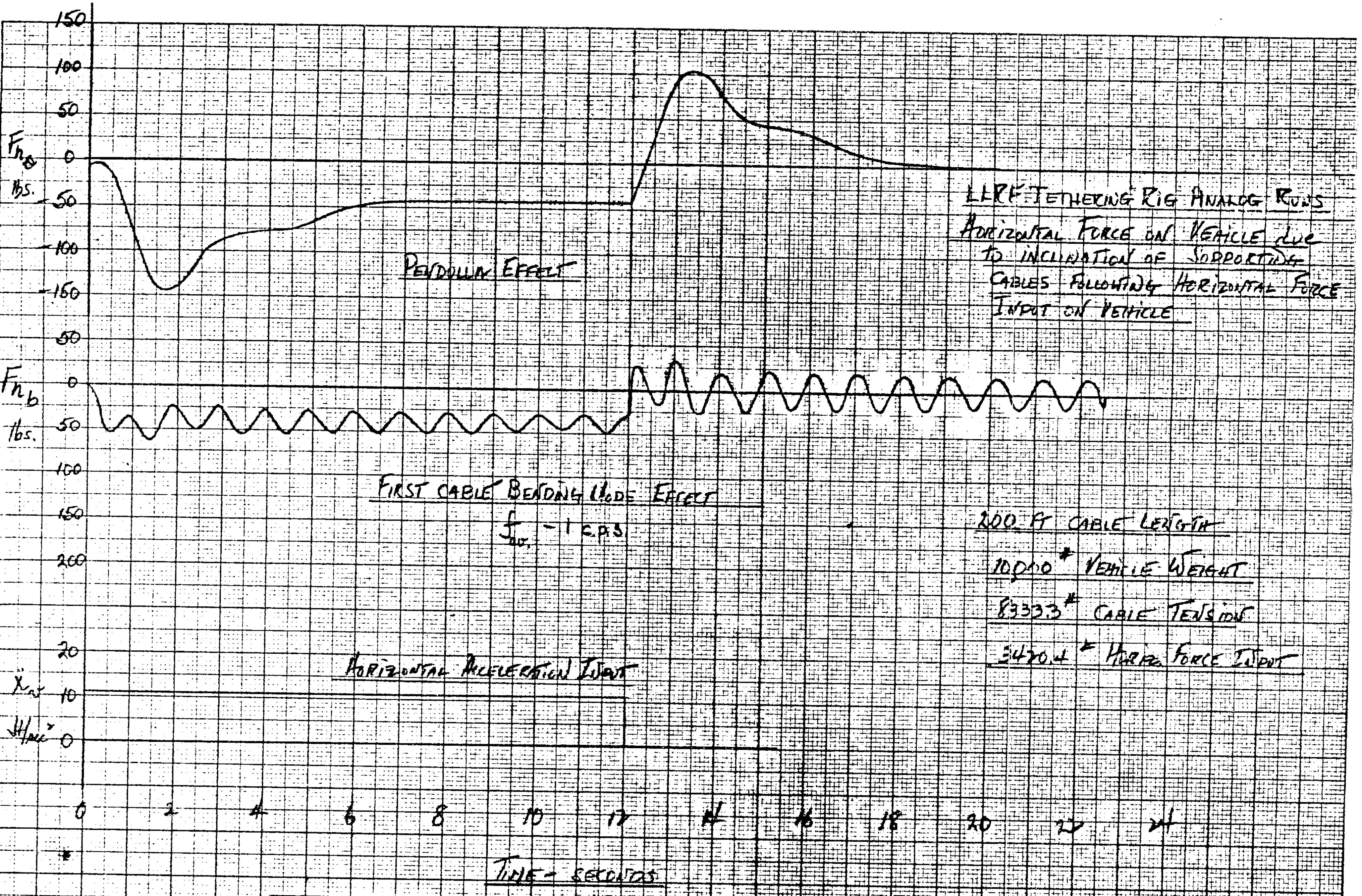

LLRF TETHERING RIG ANALOG RUNS
HORIZONTAL FORCE ON VEHICLE DUE TO INCLINATION OF SUPPORTING CABLES FOLLOWING HORIZONTAL FORCE INPUT ON VEHICLE
PENDULUM EFFECT
FIRST CABLE BENDING MODE EFFECT
200 FT CABLE LENGTH
10000 # VEHICLE WEIGHT
83333 # CABLE TENSION
HORIZONTAL ACCELERATION INPUT
TIME - SECONDS
150
100
50
0
-50
-100
-150
lbs.
20
10
2
4
6
8
10
12
16
18
20

FIGURE D-2

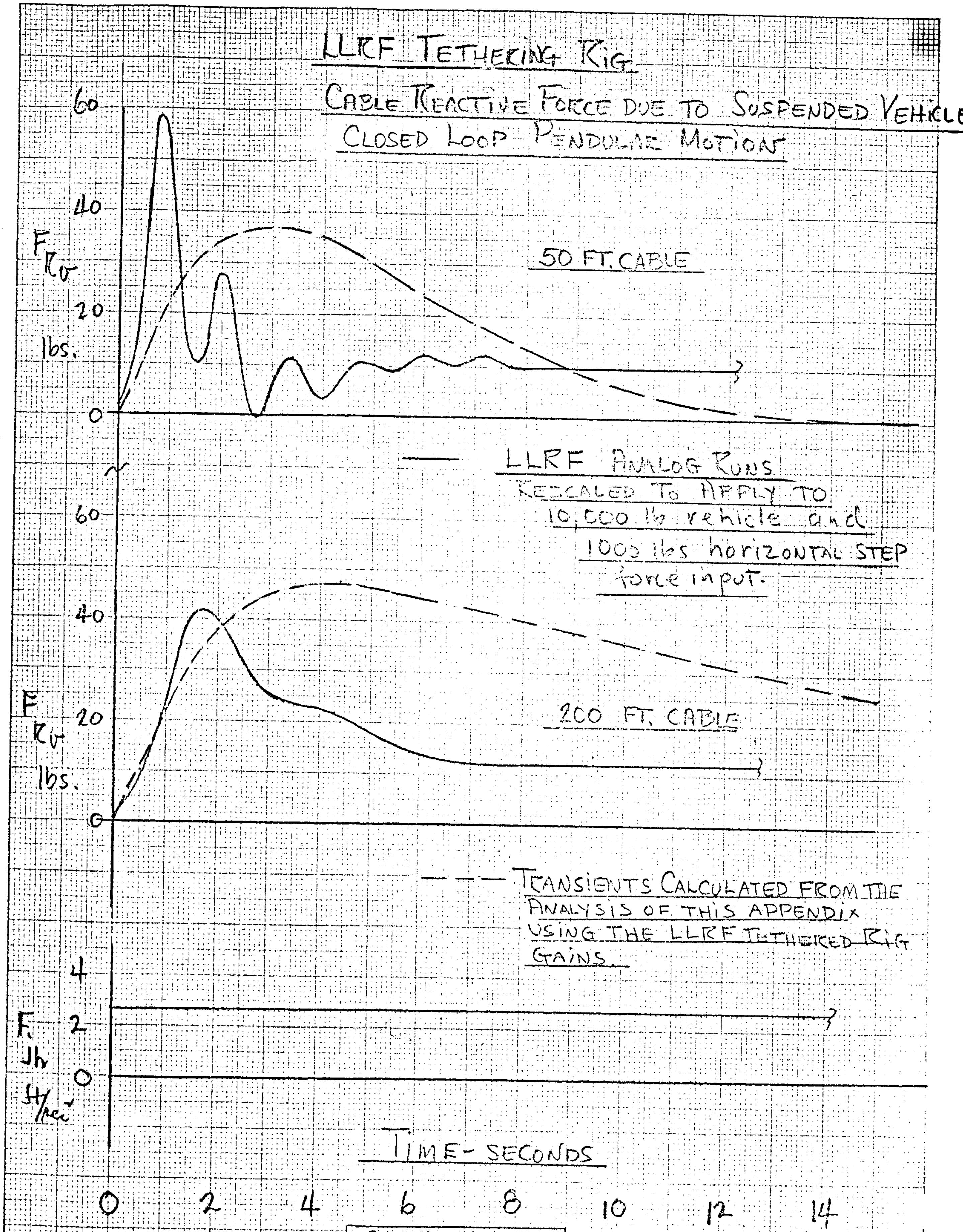


FIGURE D-3

7/12/63 P.P.

APPENDIX D.2

ANALYSIS OF INTERACTION OF TETHERING RIG PENDULUM DYNAMICS ON THE HORIZONTAL MOTIONS OF THE CABLE SUSPENDED LTA-9

D.2.1 Summary

This analysis considers the stabilization of the closed loop pendulum control system which is required for the tethering vehicle to follow the cable-suspended LTA-9 such that the horizontal reactive forces of the cable on LTA-9 are minimized. The tethering vehicle, which may be either a hovering helicopter or a carriage moving on an upper track of a stationary gantry, is commanded to follow the horizontal motions of the LTA-9 such that the supporting cable is maintained vertical and at a tension of 5/6 of the LTA-9 weight in order to simulate the lunar gravitational environment.

The pendulum control system was designed so that gain programming with cable length would not be required. To meet this objective the gain and compensation selection was made so that the resulting variation of system response bandwidth with cable length would fall below the corresponding variation of fundamental cable bending frequency with cable length. In this preliminary analysis, it is only in regard to maintaining pendulum control system bandwidth below the fundamental cable bending frequency that cable bending dynamic effects are considered. A more complete analog investigation is necessary to design the pendulum control system on the basis of coupled cable bending-pendulum dynamics in interaction with the LTA-9 dynamics.

In regard to interaction of the pendulum control system with the LTA-9 motions, results of this analysis indicate that it is not possible to maintain the cable precisely vertical. Therefore, even though the vertical cable reactive force on the LTA-9 is held constant, a horizontal force is imparted to the LTA-9 by the cable. This force is equal to the tension force times the sine of the off-vertical cable angle . It was found that the magnitude of the horizontal cable reactive force could be reduced by increasing the gain of the pendulum control system. However, a system stability problem arises as the increased bandwidth approaches the resonant frequency of the fundamental bending mode of the supporting cable.

For example, with a 12,000 lb. LTA-9 suspended with a cable tension, density and length of 10,000 lbs., 2.4 lbs/ft., and 200 ft. respectively from a 20,000 lb. carriage on the stationary rig, the carriage control system designed to provide a double integration in the position control loop with an approximate

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bandwidth of 0.167 c.p.s. will present maximum cable reactive forces of 255 lbs. and 470 lbs. following respective 1000 lb. impulse and step horizontal force inputs on the LTA-9. For an increase of system gain to obtain a higher bandwidth of 0.213, the cable reactive forces may be reduced to 60 lbs. and 118 lbs. for the same force inputs. However, with the fundamental cable bending frequency at .95 c.p.s., it is seen that further increase of control gain to reduce cable reactive force will act to reduce the stability margin in the closed loop system.

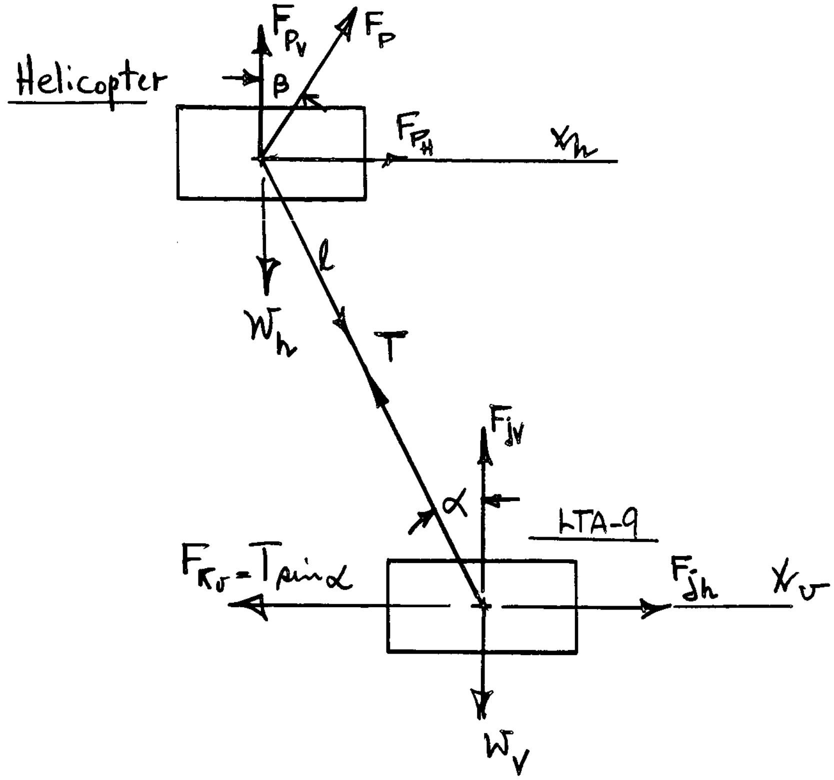
With a provision for a triple integration compensation in the position control loop, and a bandwidth of 0.45 c.p.s., a considerable reduction in cable reactive force is obtained, to 30 lbs.,following a step force input of 1000 lbs. However, with this system, due to the triple integration which indicates 270° of phase lag, a potential system instability is seen when combined with the presence of component dead-zones which are expected.

Similarly, for the 15,000 lb. helicopter tethering, the LTA-9 with a cable of 300 feet and weight of 1.0 lb/ft., the helicopter control system designed to provide a double integration in the position control loop with a 0.31 c.p.s. bandwidth, will present maximum cable reactive forces of 134 lbs. and 259 lbs. for respective 1000 lb. impulse and step horizontal force inputs into the LTA-9. When the control system loop gain is increased to decrease the corresponding reactive forces to 100 lbs. and 97 lbs., the resulting bandwidth of .46 c.p.s. approaches the fundamental cable bending frequency of .95 c.p.s. With the provision for a triple integration compensation in the inner position control loop, and a bandwidth of 0.36, the maximum cable reactive force may be reduced to 89 lbs. following a step force input of 1000 lbs.

As results indicate, the pendulum control system which provides for the double integration in the inner position control loop with the higher gain selection, system B, in Table D-1, is recommended, since it is best to avoid the potential stability problem presented with the triple integration compensation. However, this recommendation will need substantiation since the effect of the cable dynamics on the pendulum control system stability was not considered in this analysis.

D.2.2 LTA-9 Tethered with Helicopter

This analysis will consider a helicopter as a tethering vehicle for the cable suspended LTA-9. For forward motion on the LTA-9, the pendulum angles of the suspending cable are measured and used to command the inclination of the helicopter rotor to accelerate the helicopter such that the cable angle is nulled. Since the pendulum and rotor inclination angles are expected to be small, the helicopter thrust and cable tension components in the vertical direction are assumed constant. The forces on the helicopter - LTA-9 pendulum system are depicted in the following drawing:



The following symbols are defined:

F_p = helicopter rotor force, lbs.

F_{jh} = LTA-9 jet force, lbs.

F_{r_v} = reactive force of cable on LTA-9, lbs.

W_h = helicopter weight, lbs.

M_h = helicopter mass, slugs

W_v = LTA-9 weight, lbs.

M_v = LTA-9 mass, lbs.

T = cable tension, lbs.

X_h = horizontal displacement of helicopter, ft.

X_v = horizontal displacement of LTA-9, ft.

α = cable pendulum angle, rad.

β = helicopter rotor angle, rad.

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For the helicopter - LTA-9 accelerating in the horizontal direction, summation of the horizontal forces on the helicopter and the LTA-9 indicates the following relationships:

1) $F_{p_h} + T_{\sin\alpha} = m_n \ddot{x}_h$

2) $F_{j_h} - T_{\sin\alpha} = m_v \ddot{x}_v$

Since the helicopter - LTA-9 system is assumed hovering, summation of vertical forces on helicopter and the LTA-9 yield the following relationships:

3) $F_{p_v} - W_H - T_{\cos\alpha} = 0$

4) $F_{j_v} + T_{\cos\alpha} - W_v = 0$

In order to determine the force components created by the helicopter rotor, it is considered that the helicopter will create a mass flow, M_p, with an aft velocity of V_p, so that:

5) $F_p = V_p \dot{m}_p$

Therefore the components of the rotor force as a function of rotor inclination, β, are:

6) $F_{p_v} = V_p \dot{m}_p \cos\beta$

7) $F_{p_h} = \dot{m}_p (V_p \sin\beta - \dot{x}_h)$

Since the cable tension is adjusted to 5/6 of the LTA-9 weight, equation (3) will indicate the rotor horizontal force component

8) $F_{p_v} = W_h + 5/6\, W_v \cos\alpha = W_h' + W_v' = W_T'$

Equating equations (6) and (8) with (7) and assuming small angles for α and β, will yield the rotor horizontal force component:

9) $F_{R_h} = W_T' (\beta - \dot{x}_h V_p)$

If we consider that the helicopter will take a certain time, τ_p, to be accelerated by the rotor to a mass flow velocity, V_p, then the following relationship is obtained:

$$10)\quad \frac{F_{R_h}}{m_n} = V_p \tau_p = \ddot{X}_h$$

or

$$11)\quad V_p = \frac{F_{R_h}}{m_h \tau_p}$$

then equation (9) can be expressed as:

$$12)\quad F_{R_h} = W_T' \beta - \frac{m_h}{T_p} \dot{x}_h$$

With equation (12) the horizontal force equation on the helicopter, (1), can be finalized and converted in terms of the Laplacian operator, S, as such:

$$13)\quad \frac{M_h}{T_p} (\tau_p S + 1) S = W_T' \beta + W_v' \alpha$$

and the horizontal forces on the LTA-9 can be re-expressed as follows in Laplacian form:

$$14)\quad M_v S^2 x_v + W_v' \alpha = F_{jh}$$

With the horizontal forces in the coupled system defined, it is to be considered that the helicopter rotor angle β, will be commanded to accelerate the helicopter horizontal force as a function of the cable angle such that the difference in displacement between the helicopter and LTA-9 is nulled, thus driving the cable vertical.

The following block diagram defining the closed loop pendular motion is developed:

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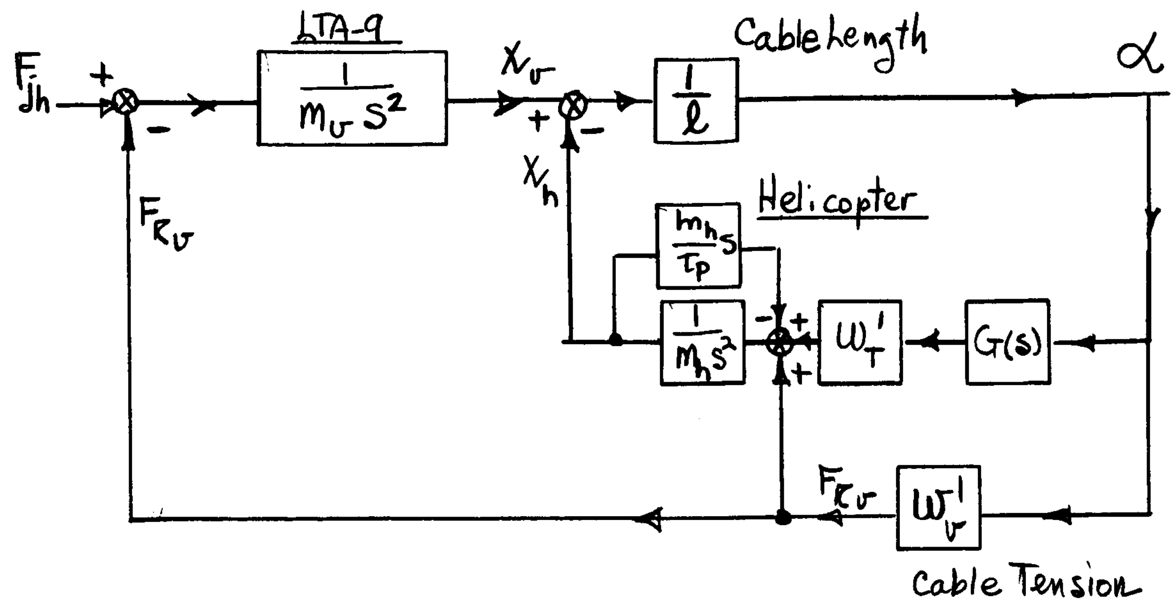
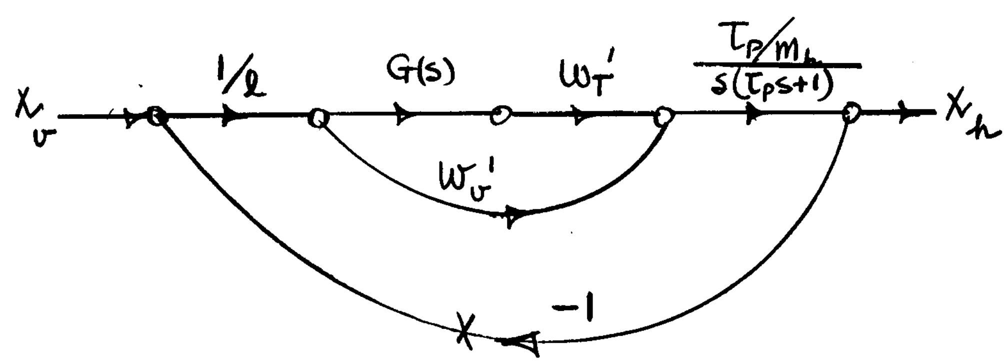


With this control system, it is now necessary to minimize the reactive force of the cable on the vehicle, F_{r_v}, and also to stabilize the closed loop pendular motion of the LTA-9 by selection of the proper gain and response characteristics for the rotor control system, G(s). The characteristics of G(s) have been selected to remain constant for cable lengths ranging from 300 to 1000 ft. The stabilization of the inner loop is considered by representing the flow diagram of the inner control loop as:



By breaking the -1 feedback patch, the open loop transfer function of the inner loop is obtained:

15) $$\left.\frac{X_h}{X_v}\right|_{open} = \left[\frac{W_v' \tau_p}{m_h \ell}\right]\left[\left(\frac{W_T'}{W_v'}\right) G(s) + 1\right]$$

The following constants are defined:

W_h = 15000 lbs.

W_v = 12000 lbs.

W_v' = 5/6 (12000) = 10000 lbs

W_t' = 15000 + 10000 = 25,000 lbs.

τ_p = 10 sec.

M_h = 466.418 slugs

M_v = 373.134 slugs

ℓ = 300 ft. to 1000 ft.

The open inner loop transfer function for the two cable lengths becomes:

$$\ell = \overset{(1000')}{300'} \quad \frac{X_h}{X_v} = \frac{\overset{(.2143)}{.7143} (2.5\ G(s) + 1)}{S(10S + 1)}$$

Selection of the rotor control function G(s) is based on stabilization of the inner loop and establishing a bandwidth range below the resonant frequencies of the fundamental cable bending mode for the indicated range of cable lengths.

In this case, for cable weight and tension of 1.0 lb/ft and 10000 lbs., the fundamental cable bending frequency for the maximum and minimum cable lengths are calculated to be:

ℓ = 1000 ft. W_b = .285 cps

ℓ = 300 ft. W_b = .950 cps

Selection of G(s) is based on establishing a variation of loop bandwidth with cable length below the expected variation of fundamental cable bending frequency with cable length as indicated above. To meet this objective, three rotor control functions, G(s), will be considered, from which closed loop characteristics equation roots will be calculated to obtain the variation of system bandwidth. Also, transient cable reactive forces for 1000 lbs. step and impulse horizontal force inputs on the LTA-9 were calculated to show the effect of the G(s) selections.

To obtain the horizontal reactive force of the cable on the LTA-9, F_{rv}, as a function of the control input force on the LTA-9, F_{jh}, the closed outer loop transfer function in symbolic form is derived to be:

$$16)\quad \frac{F_{Rv}}{F_{jh}} = \frac{(\tau_p s+1)(T_3 S+1)}{s^4\left(\frac{l m_v \tau_p T_3}{W_v'}\right) + s^3\left(\frac{l m_v \tau_p + l m_v T_3}{W_v'}\right) + s^2\left(\frac{l m_v}{W_v'} + \tau_p T_3 + \frac{M_v}{M_h}\tau_p T_3 + K_c T_1 T_2 \tau_p \frac{W_T'}{W_s'}\frac{m_v}{m_h}\right) + s\left(\tau_p + \frac{m_v}{m_h}\tau_p + \frac{W_T'}{W_v'}\frac{m_v}{m_h} K_c \tau_p (T_1 + T_2)\right) + \left(1 + W_T/W_v' \; M_v/M_h \; K_c \tau_p\right)}$$

The G(s) function constants T_1, T_2, T_3 and K_c are to be defined.

From which the steady state cable reactive force on the LTA-9 as a function of step input force on the LTA-9 is obtained as:

$$17)\quad F_{R_v}\Big|_{S.S.} = F_{jh}\left[\frac{1}{1 + \frac{W_T'}{W_v'}\frac{M_v}{M_h} K_c \tau_p}\right]$$

The first selection made for G(s) will provide a double integration in the position control inner loop. Gain and compensation was selected to meet bandwidth requirements and to minimize cable reactive forces. The G(s) function is of the form:

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18) $$G(s) = \frac{K_c (T_1S + 1) (T_2S + 1)}{S(T_3S + 1)}$$

where K_c = .143 rad/rad.

$T_1 = T_2$ = 7.143 sec.

T_3 = .40 sec.

The second selection for G(s) is of the same form, however, a higher gain, K_c, was selected, where the compensation time constants were adjusted to meet bandwidth requirements. The effect of the higher K_c gain was investigated to reduce the resulting cable reactive forces. The gain and compensation selections made were:

K_c = .467 rad/rad.

T_1 = 2.08 sec.

T_2 = 8.85 sec.

T_3 = 0.25 sec.

The third selection for G(s) provided for a triple integration in the position control loop. This will make possible zero steady-state cable reactive forces on the LTA-9 for step input force commands. However, with 270° of phase lag in the inner position control loop, a potential unstable limit cycle problem will arise for system operation within loop component dead-zones. The form of G(s) is:

19) $$G(s) = \frac{K_c (T_1S + 1) (T_2S + 1) (T_3S + 1)}{S^2}$$

where: K_c = .02 rad/rad.

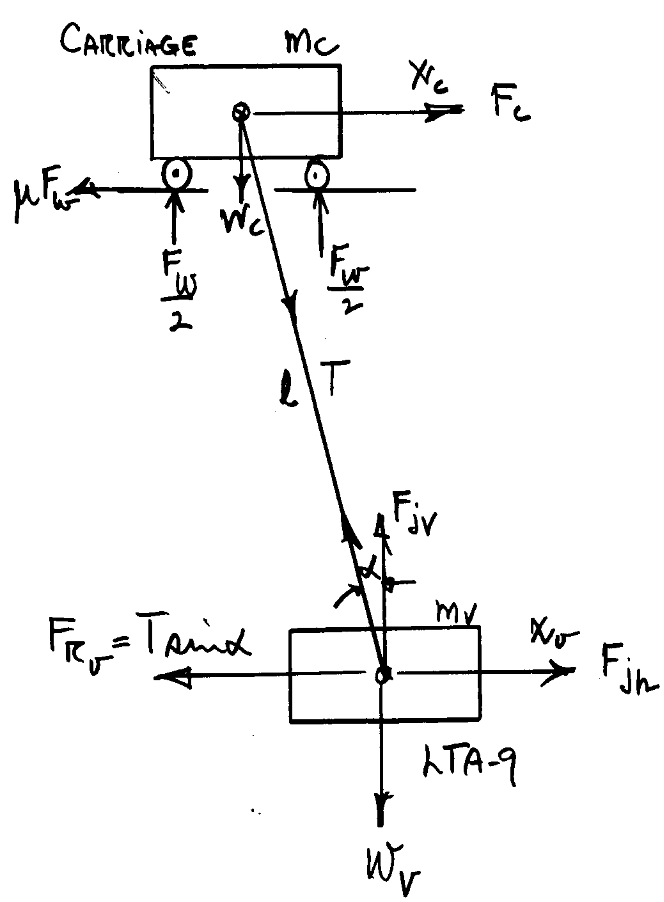
$T_1 = T_2$ = 6.67

T_3 = 16.67

Cable reactive force transients for 1000 lb. step and impulse horizontal force inputs on the LTA-9 were obtained for the pendulum control system with the three selections made for the rotor control function G(s), and are presented in Figure D-8. Table D-1 presents closed loop characteristic equation roots, maximum and steady-state cable reactive forces and approximate system bandwidth for the three G(s) selections at cable lengths of 300, 600 and 1000 ft.

D.2.3 LTA-9 Tethered with Carriage on Stationary Rig

This analysis considers the carriage moving on a horizontal track fixed to a stationary rig as the tethering vehicle for the LTA-9. For forward motion of the LTA-9, the pendulum angle of the suspending cable is measured and used to accelerate the upper carriage to follow the LTA-9. The forces on the carriage - LTA-9 pendulum system are depicted in the following diagram:



The following symbols are defined:

F_c = force on carriage, lbs.

F_{jh} = LTA-9 jet force, lbs.

F_{R_V} = Reactive force of cable on LTA-9, lbs.

F_W = Normal force on carriage wheels - lbs.

μ = coefficient of rolling function

W_c = weight of carriage, lbs.

W_V = weight of LTA-9, lbs.

M_c = Mass of carriage, slugs

M_V = Mass of LTA-9, slugs

T = Cable tension

X_c = Horizontal displacement of carriage, ft.

X_V = Horizontal displacement of LTA-9, ft.

W_V' = $5/6\ W_V$ - lbs.

Summation of horizontal forces on the carriage, neglecting friction forces of carriage tires on the gantry track, is:

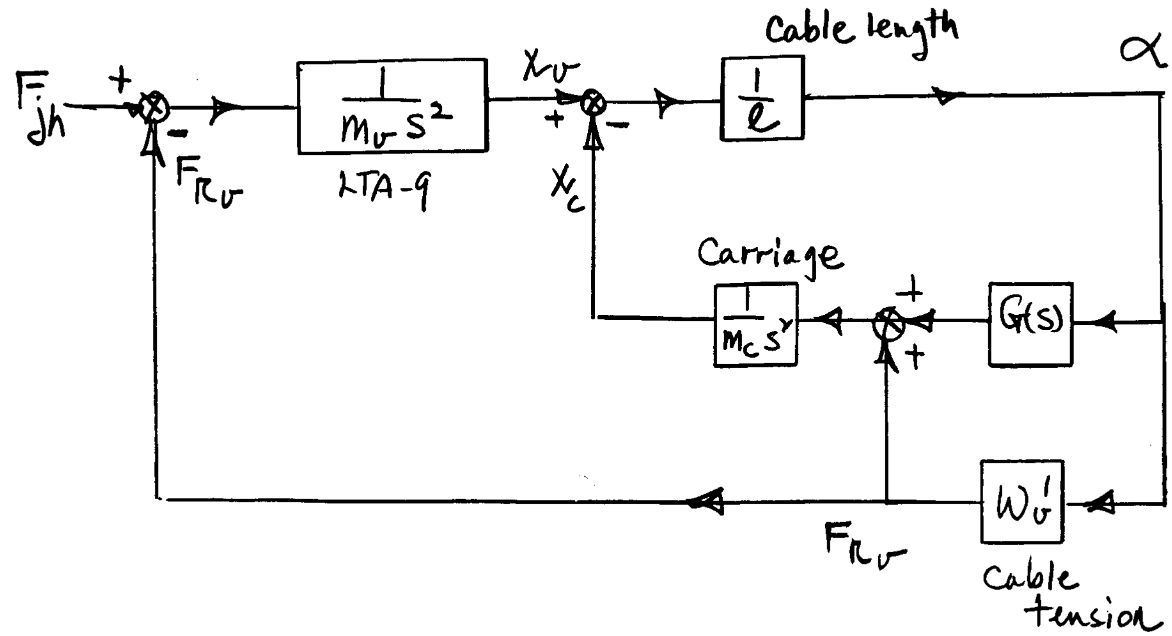
1) $F_c + T_{\sin}\alpha = M_c \ddot{X}_c$

The summation of horizontal forces on the suspended LTA-9 is:

2) $F_{jh} - T_{\sin}\alpha = M_V \ddot{X}_V$

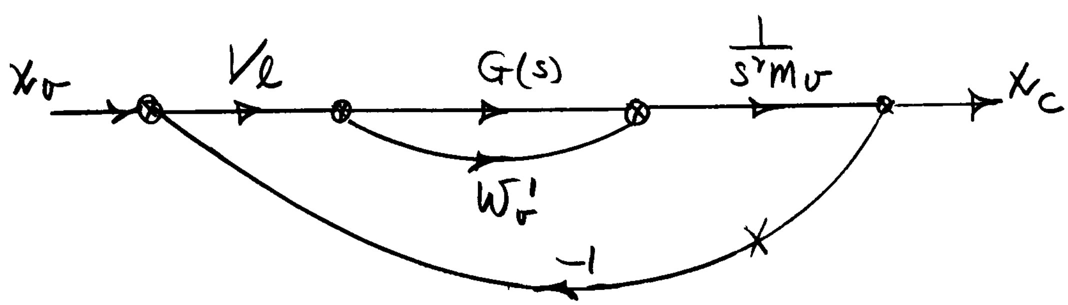
With the horizontal forces defined, it is now considered that the force on the carriage will be commanded to accelerate the carriage as a function of cable angle, α , so that the difference in displacements between the carriage and the LTA-9 will be nulled, thus driving the cable vertical.

The following block diagram defining the closed loop pendulum motion is developed:



The characteristics of the carriage control system G(s) are to be selected to assure stabilization of the pendulum control system throughout the expected range of variation of cable length, $50 \text{ ft} = \ell = 200 \text{ ft}$.

Stabilization of the inner loop is considered by representing the signal flow diagram as such:



The open loop transfer function of the inner loop is obtained by breaking the -1 feedback path:

$$3)\quad \left.\frac{X_c}{X_v}\right|_{open} = \left[\frac{W_v'}{\ell m_c}\right]\left[\frac{G(s)}{W_v'} + 1\right]$$

The following constants are defined:

W_c = 20,000 lbs.

W_v = 12,000 lbs.

W_v' = 5/6 (12,000) = 10,000 lbs.

M_c = 621.891 slugs

M_v = 373.134 slugs

ℓ = 50 ft. to 200 ft.

The open loop transfer function for the 2 cable lengths becomes:

$$\ell = 50' \qquad \frac{X_c}{X_v} = \frac{.322\left(1 + \frac{G(s)}{10000}\right)}{s^2}$$

$$\ell = 200' \qquad \frac{X_c}{X_v} = \frac{.0804\left(1 + \frac{G(s)}{10000}\right)}{s^2}$$

Selection of the function G(s) is based on stabilization of the inner loop and to establish a control system bandwidth range below the resonant frequency range of the fundamental cable bending mode for the two cable lengths, 50 and 200 ft. For the cable weight and tension of 2.4 lbs/ft and 10,000 lbs., the fundamental cable bending frequency for the two cable lengths are:

ℓ = 200 ft. W_B = .95 c.p.s.

ℓ = 50 ft. W_B = 3.75 c.p.s.

Three selections for the carriage control function, G(s), were investigated, in order to ascertain the effect on cable reactive forces and system bandwidth.

To obtain the horizontal reactive force of the cable on the LTA-9, F_R, as a function of control input force, F_{jh}, the closed outer loop transfer function is considered:

4) $$\frac{F_{R_v}}{F_{jh}} = \frac{(t_2 S+1)}{S^3\left(\frac{l m_v t_2}{W_v'}\right) + S^2\left(\frac{l m_v}{W_v'}\right) + S\left(\frac{K t_1}{W_v'}\frac{m_v}{M_c} + \frac{m_v}{m_c} t_2 + t_2\right) + \left(\frac{K m_v}{W_v' m_c} + \frac{m_v}{m_c} + 1\right)}$$

The steady state reactive force of the cable on the LTA-9 as a function of a step input force is:

5) $$F_{R_v} = F_{jh} \frac{1}{\frac{m_v}{m_c}\left(\frac{K_c}{W_v'} + 1\right) + 1}$$

The first two selections made for G(s) provide for a double integration in the inner position control loop. The G(s) function is of the form:

6) $$G(s) = K_c \frac{(t_1 S+1)}{(t_2 S+1)}$$

The gain and compensation time constants for the first G(s) selection are:

$K_c = 1.338 \times 10^4$ lb/rad.

$t_1 = 5.58$ sec.

$t_2 = .330$ sec.

In the second G(s) selection, the K_c gain was increased as a means to decrease cable reactive force, F_{R_V}, as is suggested by inspection of equation (5).

$$K_c = 11.433 \times 10^4 \text{ lb/rad.}$$

$$t_1 = 1.80 \text{ sec.}$$

$$t_2 = .167 \text{ sec.}$$

The third G(s) function, selected as shown, to provide a triple integration in the inner position loop, will present a potential stability problem, as discussed in the previous section. However, its use as a means to reduce cable reactive force is emphasized.

$$G(s) = \frac{K_c \ (t_1 S + 1) \ (t_2 \ S+1)}{S}$$

Where the gain and compensation time constants were selected as such:

$$K_c = 19.2 \times 10^4 \text{ lb/rad.}$$

$$t_1 = t_2 = 1.25 \text{ sec.}$$

Cable reactive force transients for 1000 lb. step and impulse force inputs on the LTA-9 were obtained for the pendulum control system with the three carriage control functions, G(s), selected, and are presented in Figure D-9. Table D-1 presents closed loop characteristic equation roots, approximate system bandwidth, and maximum and steady-state cable forces as obtained from the force transients of figure D-9. Values are shown for the three G(s) selections for cable lengths of 50 and 200 ft.

TABLE D-1

SUMMARY OF RESULTS FOR TETHERED LTA-9

PENDULUM CONTROL SYSTEM SELECTIONS

Configuration	Selected Cable Characteristics				(F_{rv}/F_{jh}) Transfer Function Closed Loop Characteristic Equation Roots					Cable Horizontal Reactive Force, F_{rv} For 1000 lb. Force Input, F_{jh}, lbs.		
					Dominant Roots					Step Input		Impulse Input
Helicopter Tether Rotor Control Function G(s)	ρ lb/ft	Length, ℓ, ft.	ω_B, Bending Freq - cps	Approx. Bandwidth cps	Freq-rps	Damp. Ratio	Freq-rps	Freq-rps	Freq-rps	Steady-State	Max.	Max.
(A) $\frac{.143\ (7.14S+1)\ (7.14S+1)}{S(.4S+1)}$	1.00	300	.95	.31	1.62	.65	.39	.083	-	259.	259.	135.
	↓	1000	.285	.092	.39	.57	2.07	.084	-	259.	260.	72.
(B) $\frac{.467\ (2.8S+1)\ (8.85S+1)}{S(.25S+1)}$	↓	300	.950	.464	2.56	.67	.57	.10	-	97.	97.	100.
	↓	600	.470	.132	.83	.79	2.69	.10	-	97.	105.	62.
	↓	1000	.285	.137	.58	.57	3.34	.10	-	97.	108.	54.
(C) $\frac{.02(16.67S+1)\ (6.67S+1)^2}{S^2}$	↓	300	.95	.363	2.28	-	.33	.075	.064	0	89.	-
	↓	1000	.285	.075	.47	.80	.078	.062	-	0	97.	-
Stationary Gantry Tether Carriage Control Function G(s)												
(A) $\frac{1.34 \times 10^4\ (5.58S+1)}{(.33S+1)}$	2.40	50	3.75	.743	2.58	.47	.58	-	-	416.	416.	178.
	↓	200	.95	.167	.65	.53	2.31	-	-	416.	470.	255.
(B) $\frac{12.34 \times 10^4\ (1.8S+1)}{(.167S+1)}$	↓	50	3.75	1.83	6.05	.43	.743	-	-	118	118	60
	↓	200	.95	.213	1.34	.82	3.81	-	-	118	118	135
(C) $\frac{19.2 \times 10^4\ (1.25S+1)^2}{S}$	↓	50	3.75	1.21	7.62	-	1.49	.55	-	0	25.	-
	↓	200	.95	.45	1.77	.54	.50	-	-	0	30.	-

APPENDIX: D.3.

ANALYSIS OF CABLE BENDING MOTION INTERACTION WITH A TETHERED LTA-9

The results of this analysis indicate that horizontal forces will be imparted to the cable-suspended LTA-9 due to the bending of the cable itself. Furthermore, the horizontal forces will be periodic and will continue indefinitely in absence of significant inherent cable damping or any other mechanical provision to damp the cable oscillations.

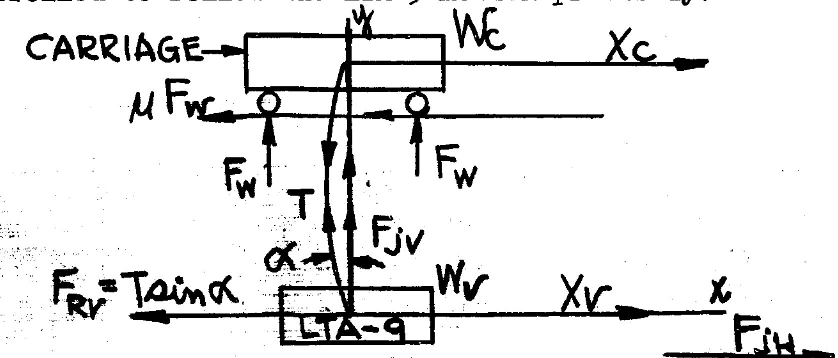
The analysis shows that even with perfect control of the LTA-9 pendular motion, a step horizontal force application on the LTA-9 will result in reactive forces on the vehicle of triangular wave form with maximum magnitude equal to the product of the horizontal step force input and the ratio of the cable weight to suspended LTA-9 weight. Since the cable weight will be low, it is expected that the cable reactive force on the LTA-9 due to cable bending will be low enough to be considered insignificant. However, the periodicity of the cable oscillations are significant, and, as analysis of the closed loop LTA-9 pendular motions indicates, the bandwidth of the pendulum control system must be designed to be below the cable bending frequency to avoid cable resonance.

For example: given a 12000 pound LEM, a 10000 pound cable tension, a 200 foot cable weighing 2.4 lbs/ft. and a 1000 pound horizontal step input force, the maximum reactive force on the LTA-9 due to cable bending would be 40 pounds with a period of 1.05 seconds. For a 50 foot cable the maximum reaction force would decrease to 10 pounds with a period of 0.27 seconds.

As a means of reducing reactive forces and supressing the cable oscillations, the cable ends can be mounted in viscous dashpots at both the LTA-9 and the carriage. The analysis shows that for proper choice of the damping coefficient, the reactive forces of the previous example can be halved and the oscillations eliminated. However, this type of cable damping cannot be recommended without proper analysis of its possible interaction with the response of the pendulum control system and to the LTA-9 control motions.

D.3.1 Undamped Cable Bending

In the analysis from which the cable reactive forces were obtained, the following sketch of the tethered LTA-9 is considered, where it is assumed that control of the LTA-9 pendular motion is perfect, that is, that the carriage can be controlled to follow the LTA-9 motion precisely.



The following symbols are defined:

W_v, LTA-9 weight, lbs.

W_c, carriage weight, lbs.

T , cable tension, lbs.

F_{jH}, horizontal force input on LTA-9, lbs.

F_w, normal force on carriage wheels, lbs.

X_c, carriage horizontal displacement, ft.

X_v, LTA-9 horizontal displacement, ft.

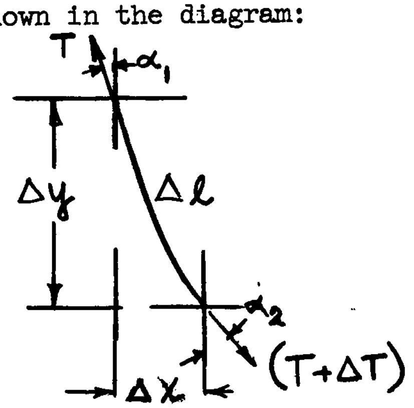
μ, friction coefficient

α , cable angle, radians

As indicated, a reactive force by the cable on the LTA-9, F_{R_V}, will occur due to the bending of the cable in the fundamental bending mode, of magnitude:

$$F_{R_V} = T \sin \alpha$$

where cable tension, T, is to be held constant at 5/6 of the LTA-9 weight to simulate the lunar gravitational field. In order to obtain the equations of motion of the cable and thus the slope of cable at the vehicle, α, a segment of the cable is considered as shown in the diagram:



Summation of Horizontal forces is considered:

(1) $$(T + \Delta T) \sin \alpha_2 - T \sin \alpha_1 = 0$$

Assuming ΔT negligible and considering small angles, we may write

$$T (\tan \alpha_2 - \tan \alpha_1) = 0$$

or:

(2) $$T \left(\frac{\partial x}{\partial y_1} - \frac{\partial x}{\partial y_2} \right) = 0$$

The force on the cable running weight, ρ, produces the acceleration:

$$\frac{\rho \Delta l}{g} \frac{\partial^2 x}{\partial y^2}$$

and if the following approximations are made:

$$\frac{\partial x}{\partial y_2} = \frac{\partial x}{\partial y_1} + \Delta y \frac{\partial^2 x}{\partial y^2}$$

$$\Delta l = \Delta y$$

The forces on the cable segment can be summed to obtain the classical wave equation which describe the transverse motion of the cable under a tension load at two ends.

$$\lambda^2 \frac{\partial^2 x}{\partial y^2} = \frac{\partial^2 x}{\partial t^2} \qquad (3)$$

where the oscillation velocity of the fundamental cable bending mode is defined as:

$$\lambda = \sqrt{\frac{Tg}{\rho}}$$

Solution of the wave equation to obtain the horizontal motion of the cable in terms of the laplacian operator, S, and the vertical cable motion, y, is performed by reducing the partial differential equation to a linear differential equation with constant coefficients as follows:

Consider the laplacian transformation:

$$X(y,s) = \mathcal{L}\, x\,(y,t)$$

then

$$S^2\, x\,(y,s) = \mathcal{L} \frac{\partial^2 x}{\partial y^2}(y,t)$$

and

$$\mathcal{L} \frac{\partial^2 x}{\partial y^2}(y,t) = \frac{\partial^2 x}{\partial y^2}\,(y,s)$$

The wave equation then becomes:

$$\frac{\partial^2 x}{\partial y^2}\,(y,s) = \frac{S^2}{\lambda^2}\,(y,s) \qquad (4)$$

The general solution of the wave equation in terms of the laplacian operator is

$$x(y,s) = A(s)\, e^{-\frac{y}{\lambda}s} + B(s)\, e^{+\frac{y}{\lambda}s} \qquad (5)$$

Where A(s) and B(s), are arbitrary constants which will be determined by the end conditions on the cable.

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Considering the origin at the vehicle, the end displacements of the cable are:

$$y = o \qquad x = x_v$$

$$y = 1 \qquad x = x_c$$

Then substitution into the general solution will yield algebraic expressions for constant (A(s) and B(s).

$$(6) \qquad x\,(o,s) = x_v = A(s) + B(s)$$

$$(7) \qquad x\,(1,s) = x_c = A(s)\,e^{-\frac{\ell}{\lambda}s} + B(s)\,e^{+\frac{\ell}{\lambda}s}$$

Solution of equations (6) and (7) yield expressions for A(s) and B(s) in terms of the laplacian operator, s, and constant 1 and

$$A(s) = \frac{x_v\,e^{+\frac{\ell}{\lambda}s} - x_c}{e^{+\ell/\lambda s} - e^{-\ell/\lambda s}}$$

$$B(s) = \frac{x_v\,e^{-\frac{\ell}{\lambda}s} - x_c}{e^{-\frac{\ell}{\lambda}s} - e^{+\frac{\ell}{\lambda}s}}$$

The final equation of motion of the cable displacement is obtained by substitutions of constants A(s), B(s) into equation (5):

$$(8) \qquad x(y,s) = \frac{x_v\left[e^{-\frac{y}{\lambda}s} - e^{-\frac{(2\ell-y)s}{\lambda}}\right] + x_c\left[e^{-\frac{(\ell-y)s}{\lambda}} + e^{-\frac{(\ell+y)s}{\lambda}}\right]}{\left(1 - e^{-\frac{2\ell}{\lambda}s}\right)}$$

The equation of motion defining the cable slope is obtained by differentiation of equation (8):

$$(9) \qquad \frac{dx}{dy}(y,s) = -\frac{s}{\lambda}\left[\frac{x_v\left(e^{-\frac{y}{\lambda}s} + e^{-\frac{(2\ell-y)s}{\lambda}}\right) - x_c\left(e^{-\frac{(\ell-y)s}{\lambda}} - e^{+\frac{(\ell+y)s}{\lambda}}\right)}{\left(1 - e^{-\frac{2\ell}{\lambda}s}\right)}\right]$$

The reactive force of the cable on the carriage and LTA-9 is obtained by the following relation:

$$F_r\,(s,y) = -\,T\,\frac{dx}{dy}\,(s,y)$$

Then at y = o, the horizontal reactive force of cable on the LTA-9 is:

$$(10) \quad F_{R_v} = \frac{Ts}{\lambda}\left[\frac{x_v\left(1 + e^{-\frac{2\ell}{\lambda}s}\right) - 2\,x_c\,e^{-\frac{\ell}{\lambda}s}}{\left(1 - e^{-\frac{2\ell}{\lambda}s}\right)}\right]$$

and at y = l; the horizontal reactive force of cable on carriage is:

$$(11) \quad F_{R_c} = -\frac{Ts}{\lambda}\left[\frac{2\,x_v e^{-\frac{\ell}{\lambda}s} - x_c\left(1 + e^{-\frac{2\ell}{\lambda}s}\right)}{\left(1 - e^{-\frac{2\ell}{\lambda}s}\right)}\right]$$

The reactive forces are dependent on the relative motion between the LTA-9, x_v, and the upper carriage, x_c. In order to obtain a preliminary indication of the transient behavior of the reactive force of the cable on the LTA-9, perfect control of the vehicle pendular motion by the carriage control system is assumed, or that:

$$x_c = x_v$$

The reactive force of the cable on the LTA-9 as a function of horizontal displacement is:

$$(12) \quad \frac{F_{R_v}}{x_v} = \frac{T}{\lambda}\, s \,\frac{\left(1 - e^{-\frac{\ell}{\lambda}s}\right)}{\left(1 + e^{-\frac{\ell}{\lambda}s}\right)}$$

In order to view the transient behavior of the reactive forces on the LTA-9 various inputs into the vehicle are considered, from which the inverse laplace transformation is performed:

For a velocity input into the LTA-9 as follows:

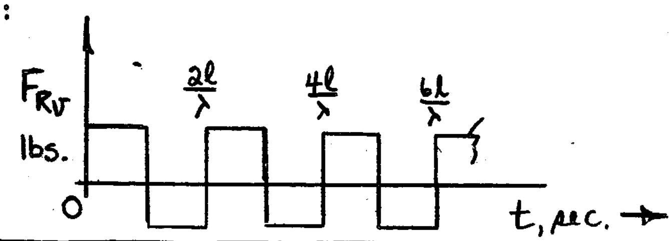
$$\frac{s\,x_v}{s} = \frac{V_v}{s}$$

Equation (12) becomes:

$$(13) \quad F_{R_v} = \frac{T}{\lambda} V_v \frac{1}{s}\,\frac{\left(1 - e^{-\frac{\ell}{\lambda}s}\right)}{\left(1 - e^{-\frac{\ell}{\lambda}s}\right)}$$

The inverse tranformation of the equation (13) will reveal the transient behavior of the reactive force of the cable on the LTA-9 as the square wave or meander function where maximum amplitude and periodicity is:

$$(14) \quad (F_{RV})_{MAX.} = \frac{TV_v}{\lambda} \qquad \tau_b = \frac{2\ell}{\lambda}$$



For a cable tension, density, and length of 10,000 lbs., , 2.4 lbs/ft., and 200 ft. respectively, 5 ft/sec. step velocity command input on the LTA-9 will present the following reactive force on the vehicle.

$$F_{R_V} = 125 \text{ lbs.}$$

$$\text{at} \quad T_b = 1.05 \text{ sec.}$$

For a step acceleration input into LTA-9 as follows:

$$\frac{s^2 x_v}{s} = \frac{F_{jh}}{W_v g} \quad \frac{1}{s}$$

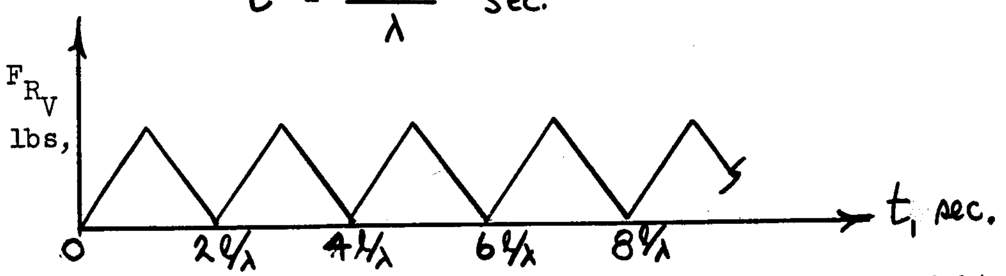
Equation (12) becomes:

$$(15) \qquad F_{R_V} \doteq \left(T/\lambda \quad \frac{F_{jh}}{W_v g} \right) \left(\frac{1 - e^{-\frac{\ell}{\lambda}s}}{\left(1 - e^{-\frac{\ell}{\lambda}s}\right)} \right)$$

The inverse transformation of the equation (15) will present the transient behavior of the reactive force of the cable on the LTA-9 as a triangular wave function of periodicity and maximum amplitude of:

$$(16) \qquad \left(F_{R_V} \right)_{max} = \frac{T}{\lambda} \quad \frac{F_{jh}}{W_v g} \quad \frac{\ell}{\lambda} = F_{jh} \frac{\rho \ell}{W_v}$$

$$\tau = \frac{2\ell}{\lambda} \text{ sec.}$$



With the cable of the previous example and for a LTA-9 weight, W_v = 12000 lbs., and a horizontal force input, F_{jh} = 1000 lbs., a step acceleration input of 2.68 ft/sec is indicated, for which the following periodicity and maximum reactive force is presented on the LTA-9 by the cable:

$$\left(F_{R_v} \right)_{max} = 40 \text{ lbs.}$$

$$T_b = 1.05 \text{ sec.}$$

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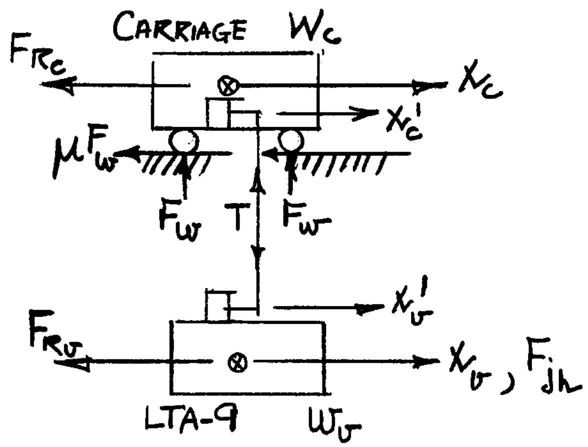
Figure D-4 was prepared to illustrate the variation of cable reactive force on the suspended LTA-9 with cable length and weight for a step horizontal force input on the vehicle. The cable tension was selected as 10000 lbs. to be compatible with the require- to suspend 5/6 of the weight of a 12000 lbs. LTA-9.

Figures D-5 and D-6 illustrate the variation of fundamental cable bending frequency as a function of cable length, weight and cable weight to tension ratio.

D.3.2

Cable Bending Damped with Viscous Dashpots

As means of eliminating the cable bending oscillations, the end of the cable are considered to be mounted in viscous dashpots as shown in the following sketch:



The dashpots have damping coefficients denoted by Dc, and Dv, lbs-sec/ft. which will inpart the following reactive force on the vehicle and carriage.

$$F_{R_v} = D_v \left(\dot{X}_v - \dot{X}_v'\right) \qquad (17)$$

$$F_{R_c} = D_c \left(\dot{X}_c - \dot{X}_c'\right) \qquad (18)$$

From the analysis of the previous section, the reactive forces of the cable on the LTA-9 and the carriage are:

$$F_{R_v} = \frac{T}{\lambda} s \left[\frac{x_v'\left(1 + e^{-\frac{2\ell}{\lambda}s}\right) - 2\, x_c'\, e^{-\frac{\ell}{\lambda}s}}{\left(1 - e^{-\frac{2\ell}{\lambda}s}\right)} \right] \qquad (19)$$

$$F_{R_c} = \frac{T}{\lambda} s \left[\frac{X_c'\left(1 + e^{-\frac{2\ell}{\lambda}s}\right) - 2\, x_v'\, e^{-\frac{\ell}{\lambda}s}}{\left(1 - e^{-\frac{2\ell}{\lambda}s}\right)} \right] \qquad (20)$$

To express the cable reactive forces in terms of the LTA-9 and carriage motion, X_v and X_c, the force equations (17) through (20) are solved simultaneously, from which the following expressions for the cable reactive force on the LTA-9 is obtained:

$$(21)\qquad F_{R_v} = \frac{Ts}{\lambda}\left[\frac{x_v\left[\left(1+e^{-\frac{2l}{\lambda}s}\right)+\frac{T/\lambda}{D_c}\left(1-e^{-\frac{2l}{\lambda}s}\right)\right]-2x_c e^{-\frac{l}{\lambda}s}}{\left[\left(1-e^{-\frac{2l}{\lambda}s}\right)+\left(\frac{T/\lambda}{D_c}+\frac{T/\lambda}{D_v}\right)\left(1+e^{-\frac{2l}{\lambda}s}\right)+\frac{(T/\lambda)^2}{D_c D_v}\left(1+e^{-\frac{2l}{\lambda}s}\right)\right]}\right]$$

It is seen that with rigid cable connection, equation (21) will reduce to the expression for the reactive force with zero cable damping (10), as developed in the previous analysis.

When the following selections is made for the damping coefficients, D_v and D_c:

$$D_v = D_c = T/\lambda$$

The reactive force of the cable on the LTA-9 will become:

$$(22)\qquad F_{R_v} = \frac{T}{2\lambda}\, s \left(x_v - x_c\, e^{-\frac{l}{\lambda}s}\right)$$

For perfect control of the LTA-9 pendular motion where:

$$x_c = x_v$$

The reactive force on the vehicle is:

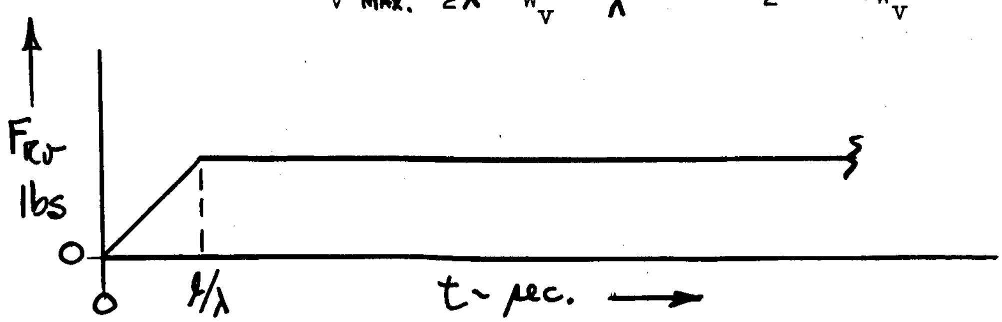
$$(23)\qquad F_{R_v} = \frac{T}{2}\, x_v\, s \left(1 - e^{-\frac{l}{\lambda}s}\right)$$

For a step acceleration input into vehicle the reactive force becomes:

$$(24)\qquad F_{R_v} = \frac{T}{2}\, \frac{F_{jh}}{W_v g} \left(1 - e^{-\frac{l}{\lambda}s}\right)$$

The inverse Laplace transform for equation (22) is a simple ramp response which reaches the maximum amplitude at $t = l/\lambda$:

$$(25)\qquad \left(F_{R_v}\right)_{MAX.} = \frac{T}{2\lambda}\, \frac{F_{jh}}{W_v}\, \frac{l}{\lambda} = \frac{F_{jh}}{2}\, \frac{\rho l}{W_v}$$



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As indicated in comparison of equation (25) with the cable reactive force with no cable damping, equation (16), it is possible to halve the cable reactive forces and eliminate the cable oscillations by mounting the cable ends in viscous dashpots.

To minimize the effects of the cable dynamics and the pendulum control system dynamics, it is suggested that the fundamental bending frequency be increased by decreasing the cable weight as much as possible.

Further study of the coupled cable bending-pendulum control system dynamic interaction on the suspended LTA-9 motion is in progress. The approach taken will be to incorporate the cable reactive force equations due to cable bending with and without mechanical damping, equations (10) and (21), into the pendulum control system block diagrams developed in Appendix D.2. From which root locus analysis will be conducted to arrive at satisfactory gain and compensation selection for the control system function, G(s), to stabilize the pendulum control system against the cable bending dynamics.

D.3.3. Undamped Cable Vertical Spring Frequency:

The frequency of this cable oscillation is obtained by considering the cable as a simple mass-spring system, where the cable tension is T and the spring constant is K, lb/ft. With no damping in the vertical direction, the vertical spring frequency is expressed by the following relationship:

$$\omega_s = \frac{1}{2\pi}\sqrt{\frac{K}{Tg}} \qquad \text{(c.p.s.)}$$

Figure D-7 was prepared to illustrate the variation of cable undamped spring frequency with cable tension and spring constant.

As indicated for the supporting cable for the LTA-9 with 10,000 lbs. tension, a spring constant of 200,000 lb/ft. will place the vertical spring cable frequency at 4.0 c.p.s., which is well above the frequencies encountered with control of the pendular motion of the LTA-9.

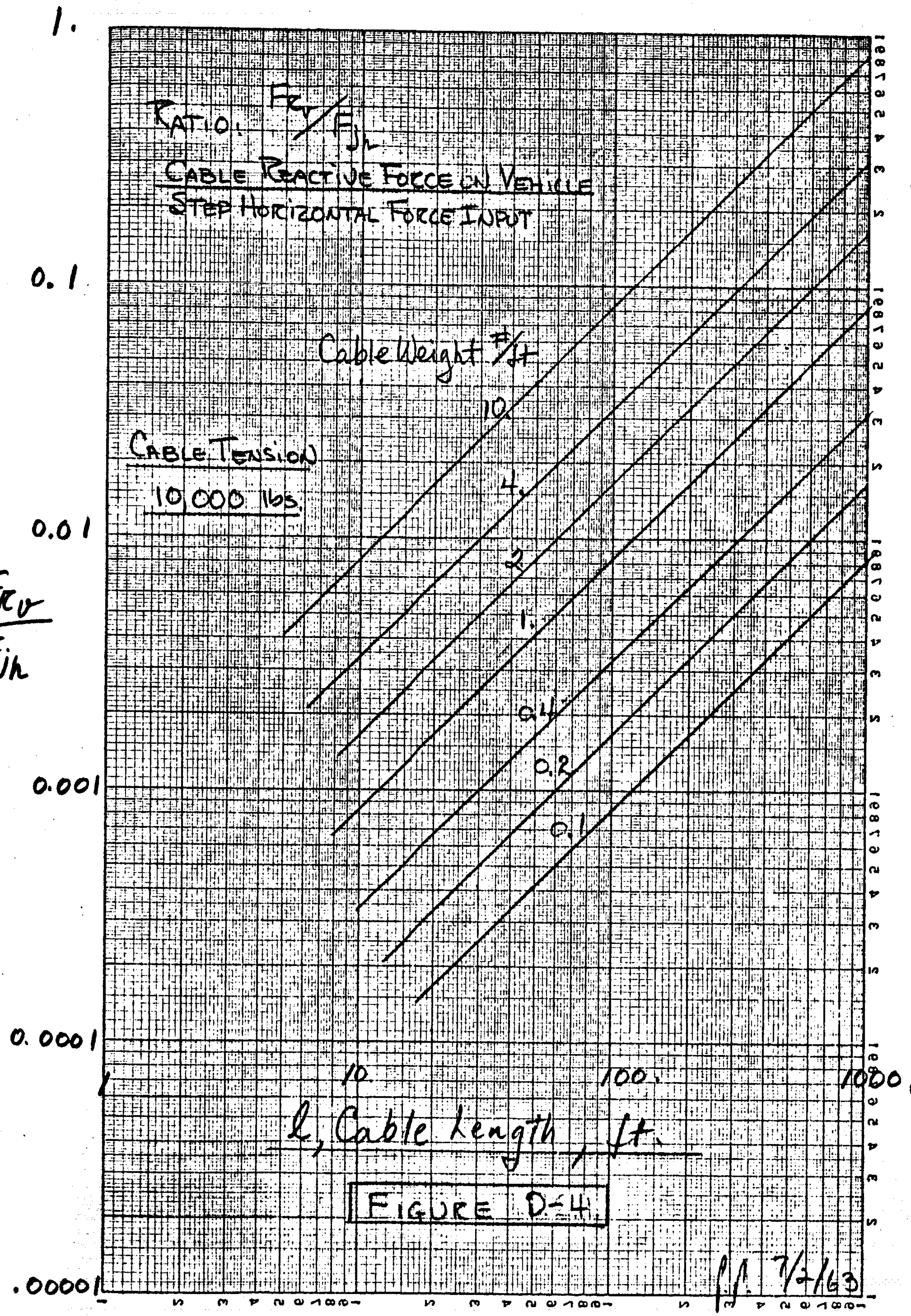
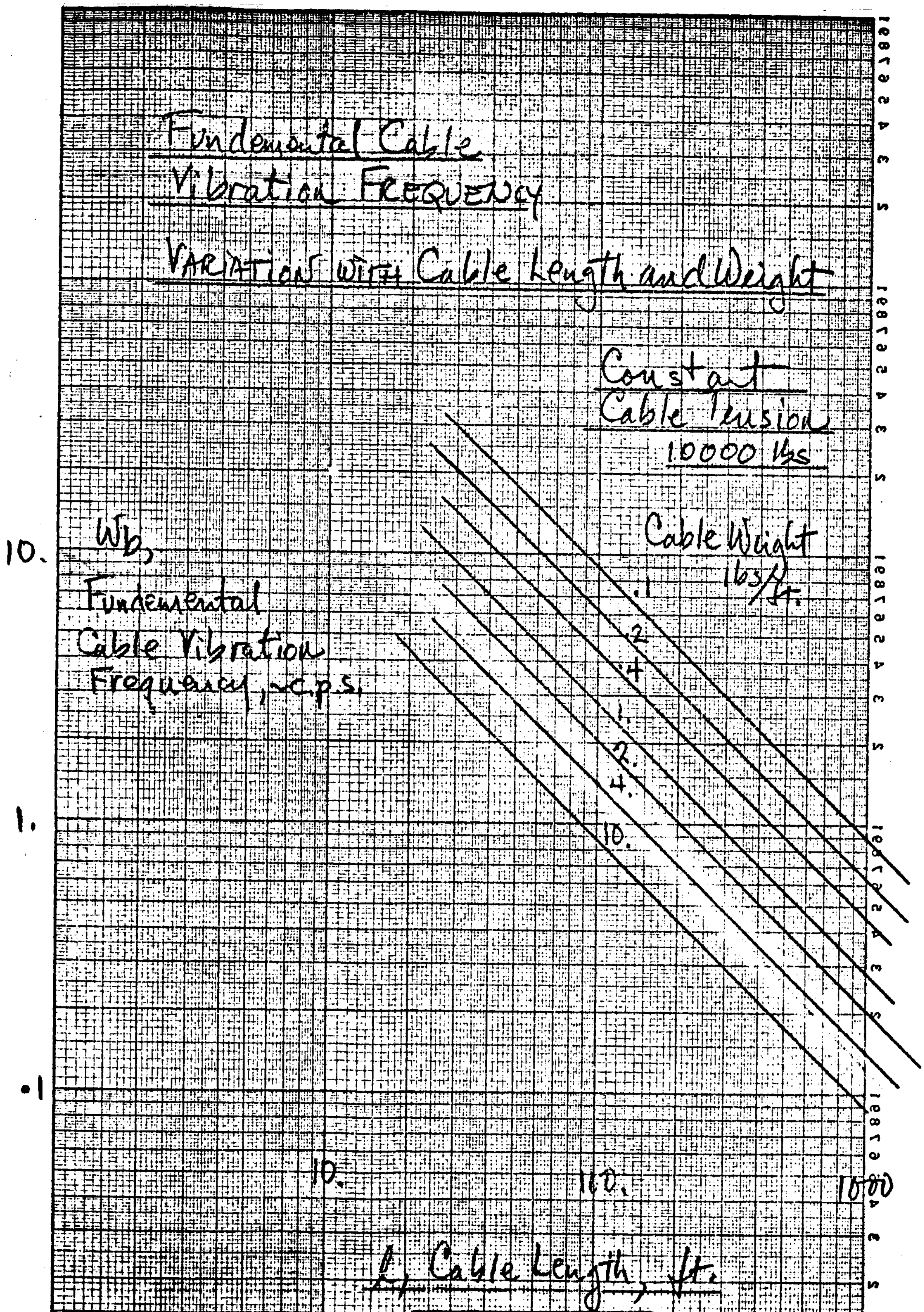

1.
RATIO: F_{RV}/F_{jh}
CABLE REACTIVE FORCE ON VEHICLE
STEP HORIZONTAL FORCE INPUT
0.1
Cable Weight #/ft
10
CABLE TENSION
10,000 lbs.
4.
0.01
2
F_{RV}/F_{jh}
1.
0.4
0.2
0.001
0.1
0.0001
.00001
1
10.
100.
1000.
l, Cable Length, ft.
7/2/63

FIGURE D-4.



Fundemental Cable
Vibration FREQUENCY
VARIATION WITH Cable Length and Weight
Constant
Cable Tension
10000 lbs
Cable Weight
lbs/ft.
.1
.2
.4
1.
2.
4.
10.
Wb, Fundemental Cable Vibration Frequency, ~c.p.s.
10.
1.
.1
10.
100.
1000
L, Cable Length, ft.

FIGURE D-5.

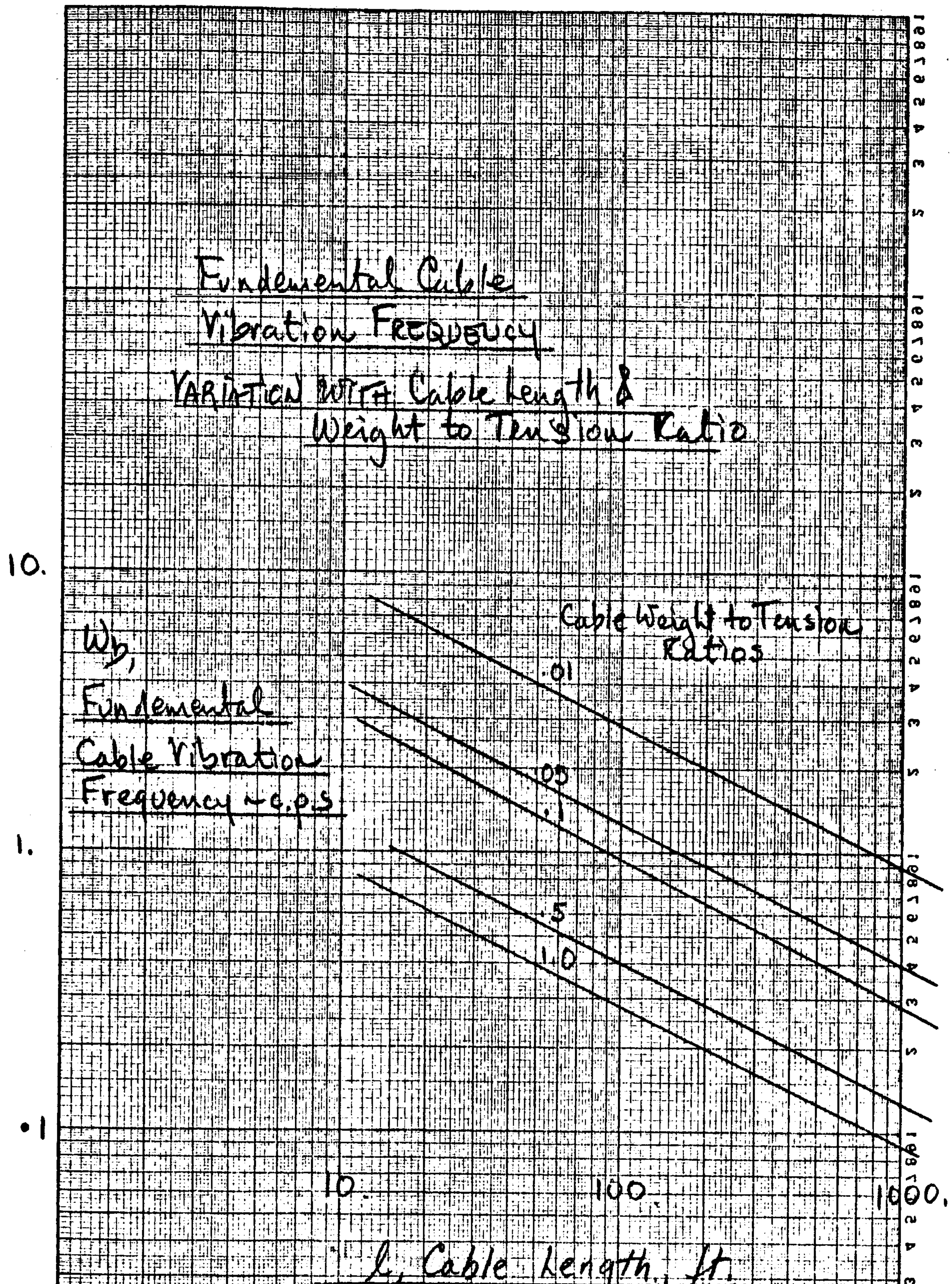
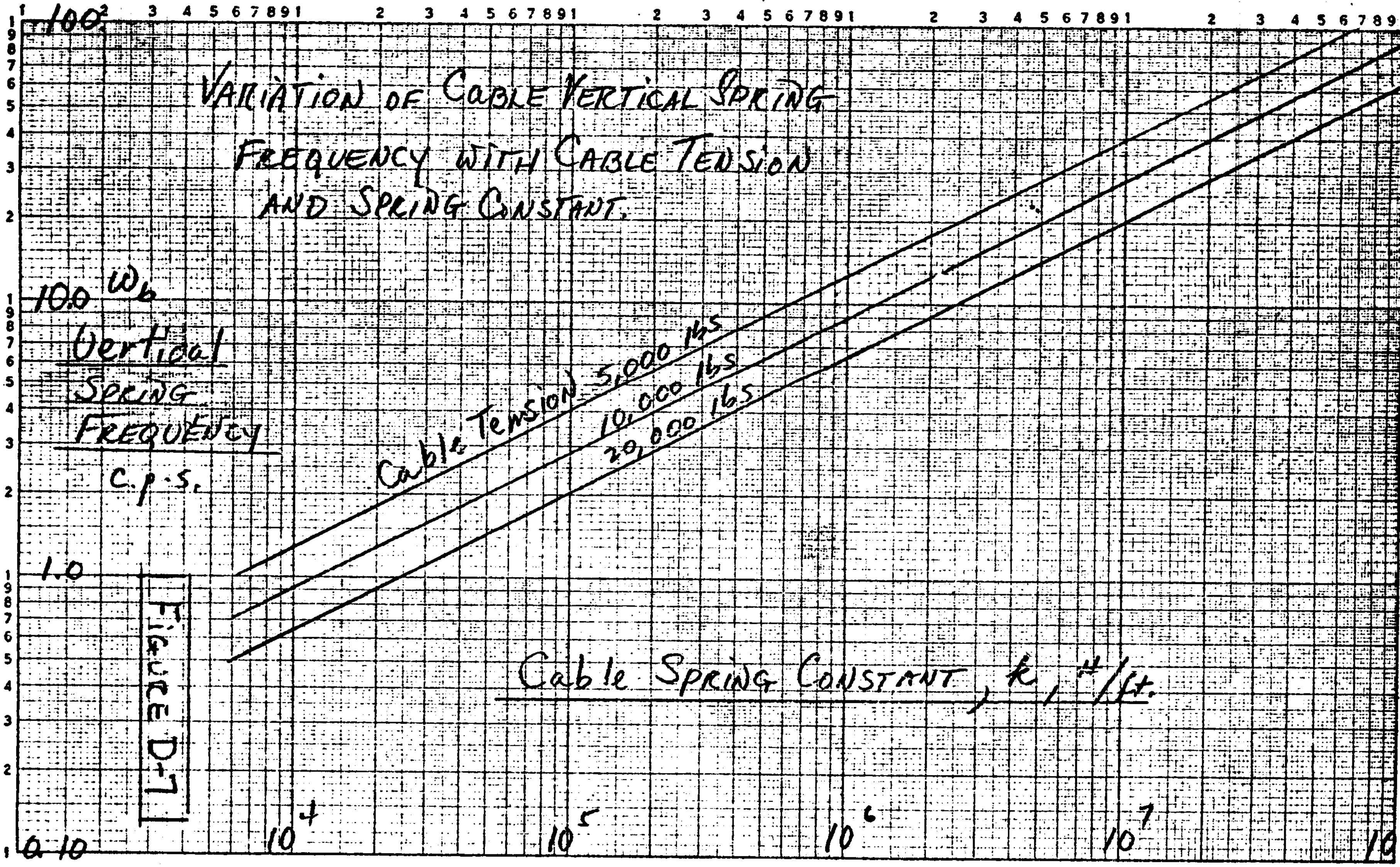

Fundemental Cable
Vibration Frequency
Variation with Cable Length &
Weight to Tension Ratio
10.
1.
.1
W_D,
Fundemental
Cable Vibration
Frequency ~ c.p.s
Cable Weight to Tension
Ratios
.01
.05
.1
.5
1.0
10.
100.
1000.
l, Cable Length, ft.

FIGURE D-6



VARIATION OF CABLE VERTICAL SPRING
FREQUENCY WITH CABLE TENSION
AND SPRING CONSTANT.
100
10.0
1.0
0.10
ω_b
Vertical
SPRING
FREQUENCY
c.p.s.
Cable Tension 5,000 lbs
10,000 lbs
20,000 lbs
Cable Spring Constant, k, #/ft.
10^4
10^5
10^6
10^7
10^8

FIGURE D-7

LTA 9 TETHERED WITH HELICOPTER
HORIZONTAL CABLE REACTIVE FORCE WITH CLOSED
LOOP PENDULUM CONTROL

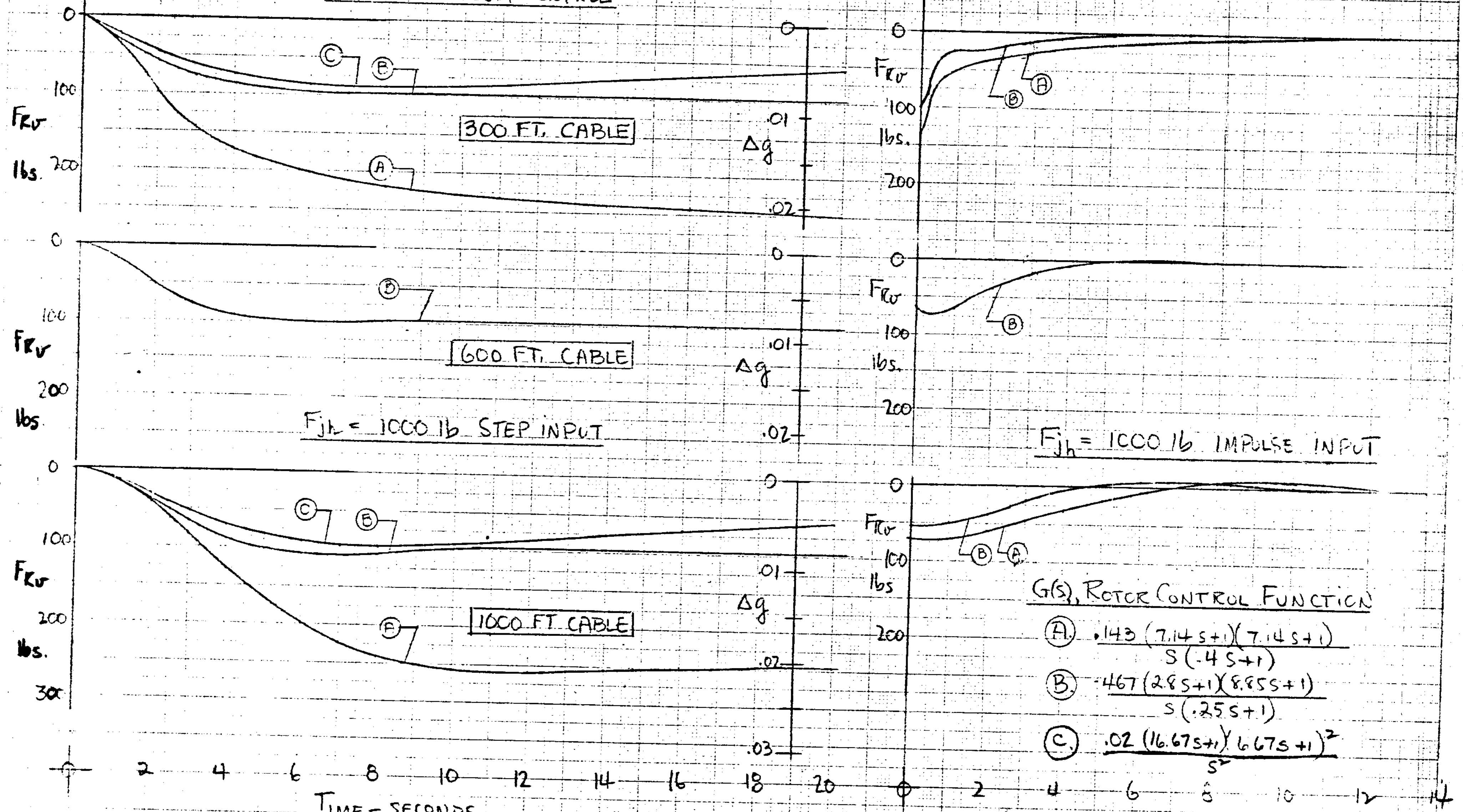
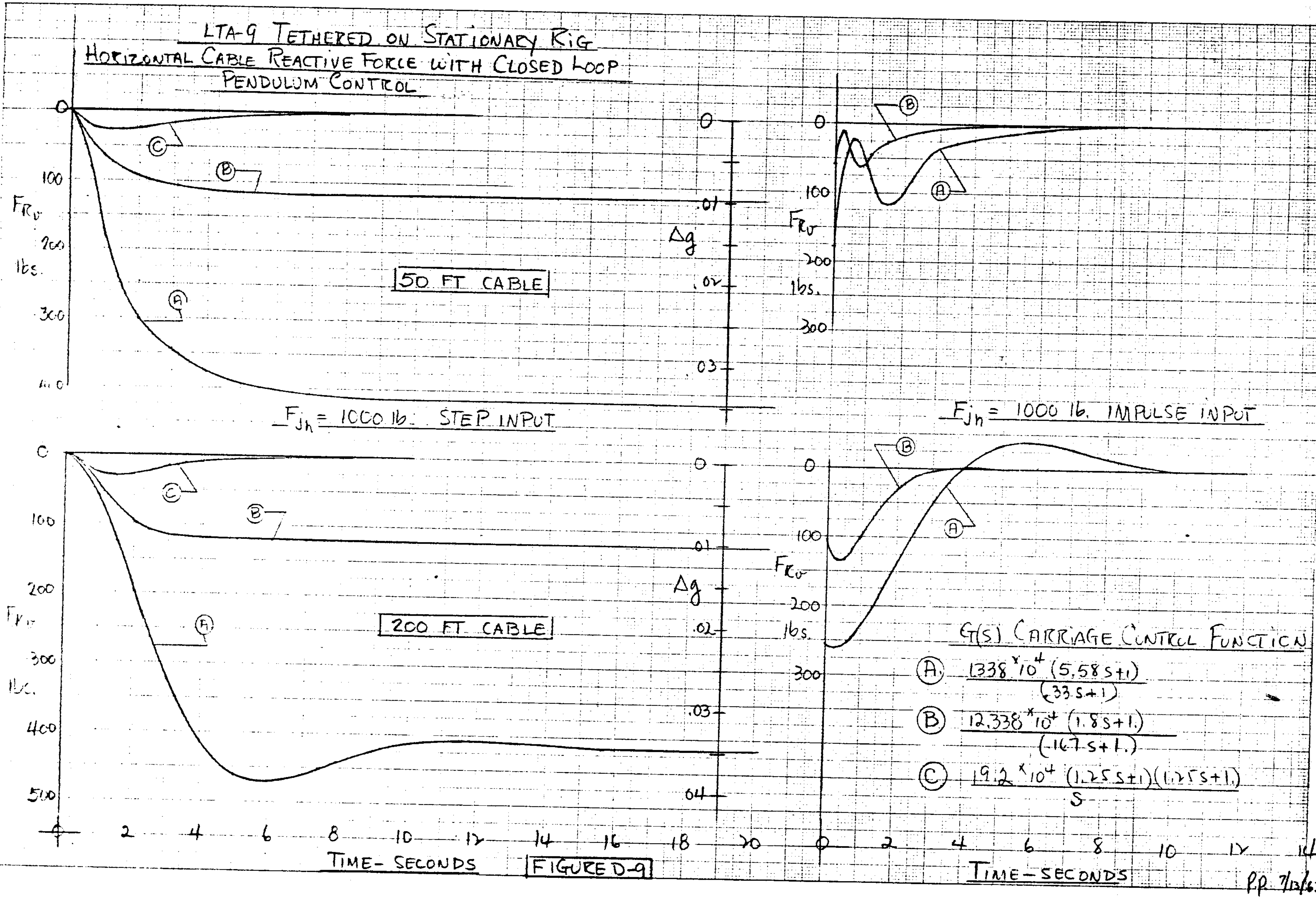


FIGURE D-8

P.D. 7/13/63


LTA-9 TETHERED ON STATIONARY RIG
HORIZONTAL CABLE REACTIVE FORCE WITH CLOSED LOOP PENDULUM CONTROL
F_{R_V} lbs.
Δg
50 FT. CABLE
200 FT. CABLE
F_{jh} = 1000 lb. STEP INPUT
F_{jh} = 1000 lb. IMPULSE INPUT
TIME - SECONDS
G(S) CARRIAGE CONTROL FUNCTION
(A) $\frac{1338 \times 10^{4}(5.58s+1)}{(.33s+1)}$
(B) $\frac{12.338 \times 10^{4}(1.8s+1)}{(.167s+1)}$
(C) $\frac{19.2 \times 10^{4}(1.25s+1)(1.25s+1)}{s}$
P.P. 7/13/63
FIGURE D-9

APPENDIX E

EFFECT OF TETHERED FLIGHT ON DYNAMIC SYSTEM TESTS

E.1 EFFECTS ON FLIGHT CONTROL SYSTEM

A factor in connection with the use of a cable tether system in a Langley or similar type facility is the effect of cable dynamics on the test vehicle and test results. If the horizontal forces imposed on the test vehicle due to cable dynamics produce system instabilities and adverse coupling effects, the usefulness of the tethered facility for simulated lunar landing tests would be questionable. Langley Research Center has done extensive analog and model tests to determine these effects quantitatively. Appendix D.1 gives these results, plotted as time histories of horizontal cable-induced forces at the vehicle c.g.

E.1.1 Force Feedback Effects

Two modes of tether cable dynamics are of concern, the pendulum mode and the "banjo" or cable bending vibration mode. Curves are shown in Appendix D, based on Langley Research Center work, showing horizontal forces due to each mode for 50 foot and 200 foot cable lengths. These curves were based on a step input of horizontal thrust to the test vehicle. The analog and model test curves can be scaled to reflect different input force levels and vehicle weights. For a 30° tilt angle with a 12,000 lb. test vehicle, giving a horizontal thrust component of 1000 lbs., the Langley test curves should be multiplied by a factor of .35.

After this scaling correction, the horizontal forces on the test vehicle due to tether cable inclination from the vertical consist of a maximum constant force of 53 lbs. plus a maximum oscillating force of $\pm$ 6 lbs. at 1.87 cps with a 50 foot cable length. With 200 foot cable length, the maximum constant force is 27 lbs. and the maximum oscillating force if $\pm$ 4 lb. at 1 cps.

The cable angle from vertical corresponding to the above constant forces amounts only to .15° and .3° for the 200 ft. and 50 ft. cable respectively. Accelerations produced by the oscillating forces are insignificant, being in the order of .0005 g.

Reference to the Appendix D, Fig. D1-2, will show higher oscillating forces than those mentioned above immediately after the step input. Since a pure step input cannot be applied in actual test, and the vehicle requires roughly 3 seconds to obtain a 30° tilt, it can be seen that under actual conditions the cable vibrations and forces will not exhibit the initial higher forces.

An analysis of a undamped pendulum cable bending mode indicates maximum oscillating forces of 40 lbs. at the vehicle. Forces at this level would result in accelerations of .003 g, still an insignificant level.

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E.1.2 Frequency Coupling Effects

Tests at Langley Research Center using a dynamic scale model of the lunar landing tether rig and analog simulation have shown lightly damped cable frequencies in the cable bending mode of 1 to 1.87 cps. These frequencies are considerably higher than the limit cycle frequencies exhibited by LEM of .167 cps at hover and .25 cps at touchdown. The possibility of adverse coupling effects has been investigated. Since the cable vibration frequencies are several times higher than the limit cycle frequencies, no coupling is anticipated in this area.

The level of oscillating forces produced by a maximum horizontal force input corresponding to a 30° tilt angle with 2000 lbs. descent engine thrust is very low as given in E.1.1. The oscillating cable angle associated with these forces is a maximum of $\pm .04^{\circ}$, which is near the threshold level of the attitude sensors (probable range: $.02^{\circ}$ - $.05^{\circ}$) in the Stability and Control subsystem. In order for coupling to occur in rotational modes the vehicle would have to reflect the oscillating cable angle. Since the vehicle will be stabilized by the attitude hold mode within the limit cycle deadband of $\pm .1^{\circ}$, the higher frequency oscillation of $\pm .04^{\circ}$ will not be felt.

Since the vehicle will be mounted on gimbal bearings in the whiffletree links, force inputs from the cable to the whiffletree may produce oscillations of the suspension links and whiffletree about the vehicle gimbal points. It is believed that motion induced in the vehicle thru friction in the gimbal bearings will be insignificant.

In summary, it is apparent that manual mode checkout of the vehicle will be unaffected by tether cable vibration forces. The forces will be below the pilot's sensory level. The vehicle will not respond to the force levels and frequencies involved thru its attitude control system. Consideration of automatic mode checkout, which would involve sensing motion of the vehicle in closing the loop, requires further analysis to determine the possible existence of a coupling problem.

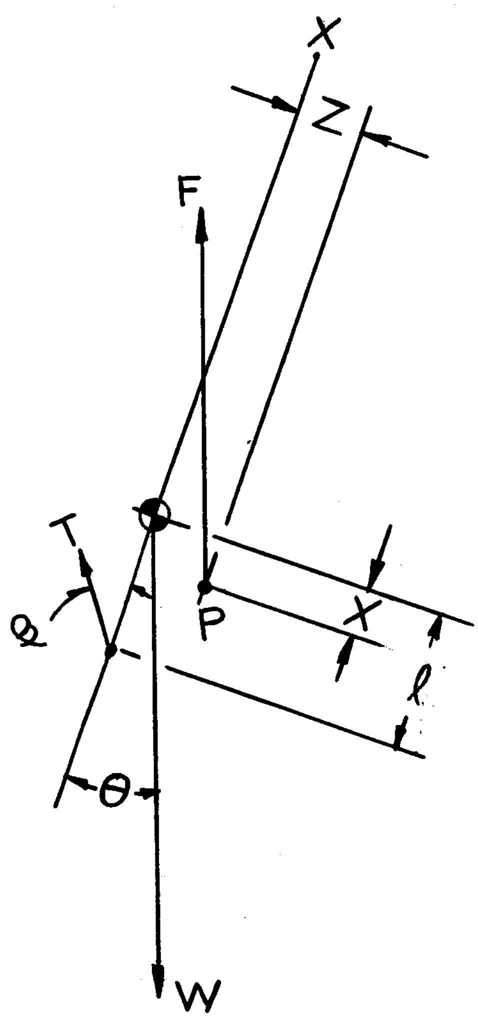
E.1.3 Fuel Sloshing Effects

The possibility of coupling between cable vibration and fuel sloshing frequencies was investigated for tethered vehicle flight conditions involving two initial propellant quantities. The "heavy" configuration, where inert ascent propellant is carried, requires 1440 pounds of descent propellant for a two-minute flight. The "light" configuration, with ascent propellant omitted, requires 1050 pounds of descent propellant for a similar period.

Initial propellant slosh frequencies for the heavy and light configurations are .725 and .710 cps respectively. These frequencies will decrease with propellant burn-off. Since the initial frequencies are below the cable bending vibration frequencies of from 1 to 1.87 cps, coupling is not expected to be a problem. It can be seen, however, that use of larger descent propellant quantities, to attain longer flight durations, may require additional descent tankage baffling to avoid coupling. The use of significantly longer cable lengths would require a similar approach.

E.1.4 Effects of Gimbal Axis Off Center of Gravity

As fuel is burned by the descent engine during the terminal descent and landing, the center of gravity moves upward about 9 inches. It could also move in a horizontal direction as a result of uneven flow from the fuel tanks, and, if the gimbal axis locating mechanism does not adequately compensate for these changes, a tilting moment will be applied to the LTA-9, which will activate the Flight Control System attitude sensors. This effect is illustrated in the following sketch.



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where,

F = tether cable tension, lbs.

ℓ = Distance from engine gimbal to c.g., ft.

T = Descent engine thrust, lbs.

W = LTA-9 weight, lbs.

x = Distance pivot is below the c.g., ft.

z = Horizontal distance from pivot to c.g., ft.

β = Descent engine gimbal angle, rad.

θ = LTA-9 tilt angle, rad.

For moments about the pivot to be zero

$$T \ell \sin \beta = F (Z \cos \theta - X \sin \theta)$$

and, for near hovering flight

$$T = F/5$$

therefore

$$\sin \beta = \frac{5Z}{\ell} \cos \theta - \frac{5X}{\ell} \sin \theta$$

this equation shows that the descent engine gimbal drive must travel 5 times farther to compensate for a given pivot offset than it would have to travel to compensate for the equivalent c nter of gravity shift.

The maximum gimbal tilt anticipated for vehicle trim during the LEM mission prior to the landing is about 1.3 degrees. The maximum LTA-9 horizontal center of gravity offset from the tether pivot axis is about .112 inches with an ℓ value of 45 inches, thus requiring 0.71 degrees of engine tilt.

It is expected that vertical offset compensation system will have an accuracy of about ±1 percent. For the total change of 9 inches and a representative tilt angle of 30 degrees, this corresponds to an engine tilt of .287 degrees.

It thus can be seen that the total descent engine tilt (.997 degrees) resulting from horizontal and vertical center of gravity offsets from the tether pivot will not exceed the angle anticipated for a normal mission if the vertical center of gravity compensation system maintains the offset at less than .09 inches.

APPENDIX F - VEHICLE APPLIED LOADS

F.1 RESTRAINED FIRING

LTA-8 will be structurally and dynamically similar to LTA-5. The launch vehicle attachment points, critical for the boost phase, will be used to hold LTA-8 during restrained firing.

The mounting system for LTA-8 firings will be a 3 to 5 cps system designed so that the support spring reaction force is directed through the c.g. of the LEM. This support was chosen because analysis indicated that there was less than 10% variation in mode shapes between the free LTA and the soft-mounted LTA. The model used for analysis was a LEM-like structure with a lowest natural frequency of 19 cps, which is our current best estimate. The cg mounting feature of the restrained system will tend to decouple rotation from translation and thereby avoid rocking modes of LTA-8. The soft mounting provisions will be analyzed for possible effects on the elastic characteristics of LTA-8.

F.2 TETHERED OPERATION

F.2.1 Critical Conditions

The environment to which the LTA-9 will be subjected is as close to the basic LEM as possible. The two major environmental changes of structural importance are (1) operating the descent engine in the atmosphere and (2) dynamic loadings arising from normal and emergency operation in the tethered mode. Critical design conditions arising from the above changes are the following:

A. Descent Stage Heating. The descent stage engine will be operated at an expansion ratio of about two during the LTA-9 tests. This engine shortening causes descent stage heating problems due to radiation from the exhaust gas plume.

B. Sonic Fatigue. Engine operation in the atmosphere will give rise to high sound pressure levels which must be considered in LTA-9 design.

C. Tethered Mode Dynamics. Dynamic loads resulting from emergency braking of the vehicle and cable dynamics during touchdown and landing must be investigated.

F.2.2 Applied Load

F.2.2.1 Descent Stage Heating

Analysis indicates that the low exit Mach No. of 2 (two) and attendant high gas temperature of $3700^{\circ}R$ causes a heat flux of approximately 4000 $BTU/HR\text{-}FT^2$ to be radiated to the stage. Firing time during this test is approximately two minutes, which means a total heat input of 133 BTU/FT^2. The descent stage and associated structure can absorb 43 BTU/FT^2 without exceeding 250°F starting at normal ambient temperatures.

The descent stage must be protected from the remaining 90 BTU/FT^2 in order to prevent overheating of the magnesium stage. Since ablating materials such as Thermolag and Avcoat have ablation heats above 1000 BTU/LB in a radiant environment, a thin spray coating of 0.020 inch thickness would be sufficient and will weigh less than 0.2 LB/FT^2. Thus the total weight would be under 10 lbs. The coating approach has the disadvantage of requiring refurbishing between engine firings. Additional thermal protection may also have to be incorporated in the area surrounding the propellant tanks.

An alternate solution investigated is to provide an ejector about the engine. The ejector would pump secondary ambient air, mix it with the hot engine exhaust gases and expell the mixture from the ejector duct exit. The approach taken to the problem was to assume complete mixing of the secondary and primary streams. The equations of mass, momentum and energy are then solved to provide a solution. This condition of complete mixing fits the case of long ejectors which provide greater thrust augmentation than short configurations. This method, which provides bulk quantities, yields conservative temperature solutions since a layer of partially heated secondary air will flow along the ejector duct wall.

Increasing the duct diameter causes more secondary air to be entrained by the ejector. There will be a physical limit to the useful increase in duct diameter, since the exit pressure drops with increasing secondary mass flow. This pressure will decrease to a point where ambient pressure can only be reached with a normal shock standing in the duct exit. An ejector/engine area ratio of about 16 is the upper limit.

The analysis indicates that it is possible to reduce the gas temperature from 3700°R to about 2400°R with this scheme. However, to achieve this reduction requires a mass flow ratio of about 3 which means that the cooling air flow necessary is in the order of 50 lb/sec for an engine thrust of 2000 pounds.

This large mass flow of air presents the following two problems: a) Modification of descent stage to provide an "inlet" for the cooling air. (The Fire-in-the-Hole ports may be adequate if enlarged for this application.) b) Aerodynamic forces and moments due to the induction of cooling air will cause severe disturbances to the vehicle stability and control subsystem. Because of these problems the use of an ejector for LTA-9 cooling is not attractive.

F.2.2.2 Sonic Fatigue

The LTA-9 vibration environment will be caused by the unsteady forces from the rocket engines and the acoustical field due to the rocket exhaust into the atmosphere. Engine induced vibration is considered proportional to the square root of mechanical power in the jet stream. Considering the LEM landing mission parameters to be 1800 lbs. thrust and Isp of 285 lbs/lb.sec., and the LTA-9 tethered landing to be 1800 lbs. thrust and Isp of 135 lb/lb.sec. results in a reduction of 30% in the LTA-9 vibration levels induced by the engines. However, the LTA-9 operates in an acoustical environment, and it is estimated that the sound power output of the rocket engines will be approximately 80 KW. If it is assumed that the directionality is uniform, sound pressure levels of 159 decibels are anticipated at the closest portion of the LTA-9 structure (2 feet from the vertical source of noise). More detailed calculations are required to obtain better estimates; however, it is believed that no extensive difficulty will be experienced in designing against this environment.The panels in the engine well area along the underside of LTA-9 will be designed against sonic fatigue. The Grumman A6A "Intruder" fuselage sidewall acoustical environment is 157 db near the engines at take-off. This area is of sheet and stringer construction with 10" ribs and 6" stringer spacing. The skins are .070" chem milled to .040 at the middle of the panels. No difficulty was experienced in service with sonic fatigue effects in this area. Measured equipment vibration levels in this area were not higher than 10 g rms over a narrow frequency range near 400 cps.

In addition to the measured A6A data, calculations were made using the Mahaffey-Smith method to convert estimated sound pressure levels to random vibration levels in g^2/cps. This analysis included 3 LTA-9 thrust levels, 1000 lbs., 3000 lbs., and a maximum atmospheric thrust level of 6800 lbs. Figure F-1 shows the results of this analysis and also compares these results with the North American Aviation estimated launch random vibration levels (for the C-5 shroud region containing the LEM) calculated using the same method, and also the NAA estimated space flight random vibration levels. Although this method of estimating vibration levels is a crude one which will be superseded by more detailed analysis, the comparison between LTA-9 and the other estimates is believed justified.

F.2.2.3 Tethered Mode Dynamics

A load factor of 3.00 limit, on the maximum fueled weight of the LTA-9, was used to size the gimbal and tether support structure. The resulting weight and moments of inertia are based on a M.S. of 1.5 on ultimate.

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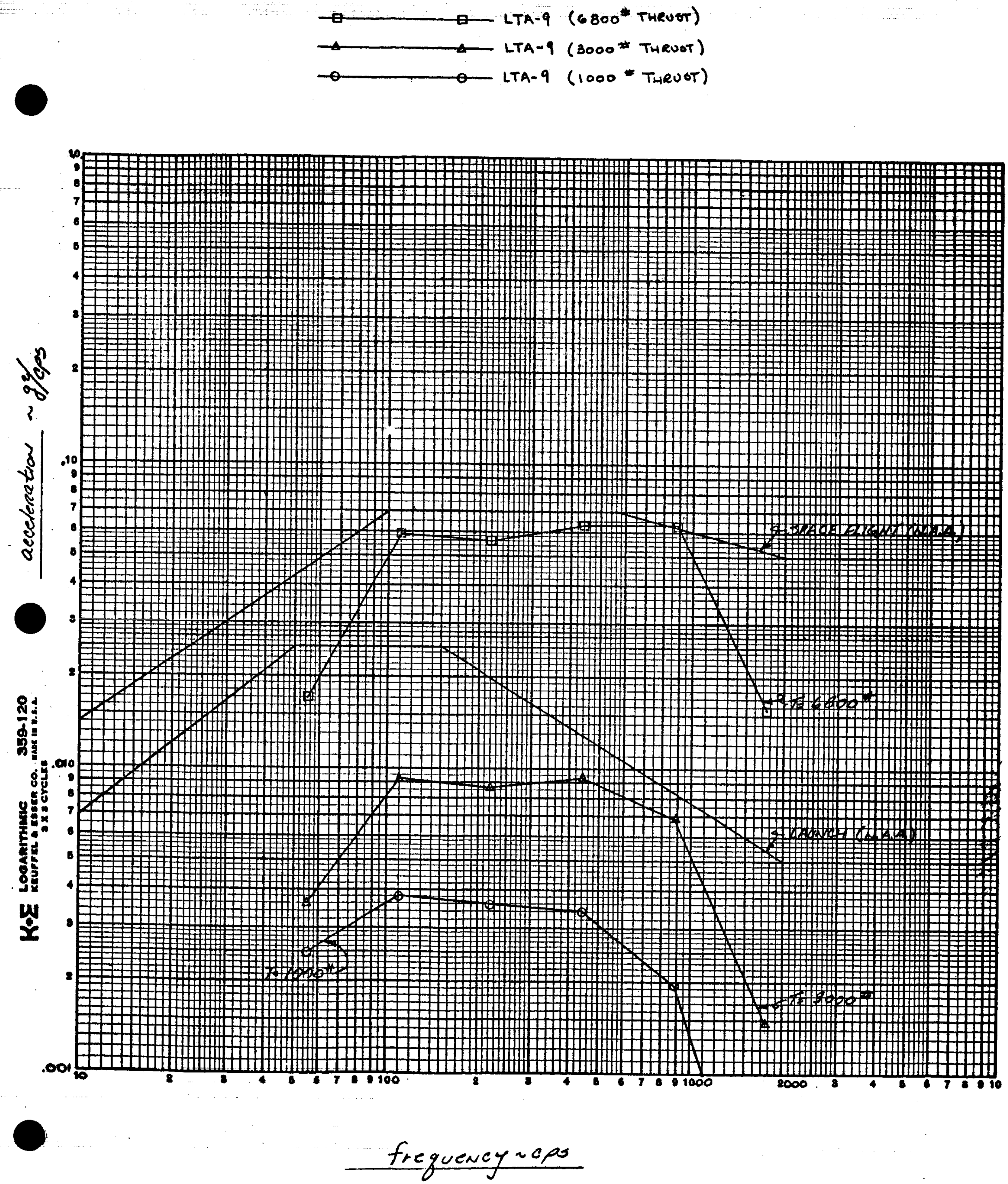

Comparison of Calculated Random Vibration Environment for LTA-9

FIG. F-1

APPENDIX G

LOCATION OF THE LTA-9 TETHERED FLIGHT FACILITY

G.1 INTRODUCTION

The Lunar Landing Research Facility (LLRF) at the Langley Research Center (LRC) is the only existing facility which approaches the LTA-9 requirements for tethered operation* and as such would appear to be a logical choice for such test work. However, the proposed LTA-9 tests require the use of LEM propellants, which present severe toxic hazards; and extensive supporting facilities and equipment, which are currently planned only for the White Sands Missile Range (WSMR). The tests also require very low wind velocities so that extraneous aerodynamic inputs can be avoided.

Since the LEM facility at WSMR will be designed specifically for toxic fuel use and also enjoys favorable weather conditions an unusually high percentage of the time, the final choice of a tethered test location should take into account the LRC facility additions dictated by the use of LEM propellants, the duplication of pertinent LEM support facilities and equipment at WSMR.

It is anticipated that the final choice of a tethered test site will involve cost information which is beyond the scope of the present preliminary design effort as defined in Reference G-1. The following discussion is presented, however, to establish the technical aspects of the decision. It will cover the following points.

1. Consequences of using LEM propellants at LRC.

2. Comparison of weather effects on test scheduling at LRC and WSMR.

3. An approach to providing a tethered facility at WSMR.

The additional special support facilities and equipment needed at LRC to test the LTA-9 are discussed in Section 7.

G.2 USE OF LEM PROPELLANTS AT THE LANGLEY RESEARCH FACILITY

Both the Reaction Control System (RCS) and the descent engine use as propellants a 50/50% blend of unsymmetrical dimethylhydrazine (UDMH) and hydrazine (N_2H_4) as fuel and nitrogen tetroxide (N_2O_4) as oxidizer. Due to their toxic nature, both these chemicals present hazards which suggest that test facilities not specifically designed for their use would handicap test operations. Specifically, these handicaps may take the form of:

* See Appendices D and E for further discussion of tethered facility requirements and Section 5 for a description of the LTA-9 tethered tests.

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1. Schedule delays due to weather presenting a toxic hazard.

2. Cost of facility additions or modifications to meet the toxic or explosive hazard.

In the following paragraphs, each of the above items will be discussed as it pertains to LEM operation in the LLRF at LRC.

G.2.1 Toxic Hazard Criteria

GAEC has reviewed various publications dealing with the safety procedures for handling the LEM propellants and has concluded that for this particular application, References G-2 and G-3 should be used. Together they cover both the recent safety criteria and operational techniques developed for the above propellants.

The safety precautions cited in Reference G-2 indicate that safe use of LEM propellants requires close adherence to criteria which are dependent upon existing weather conditions and proximity to inhabited areas. Specifically, it states the downwind clearance distance required to safely disperse given amounts of spilled propellant under given conditions of wind and temperature variation with altitude. Further, it states that while waivers to the explosion safety criteria can be obtained, "no toxic hazard waiver shall be granted".

G.2.1.1 Oxidizer Health Hazard

The following paragraphs, pertaining to the health hazards imposed by N_2O_4, are reproduced from reference G-3.

> "Liquid N_2O_4 spillage on the skin or splashing in the eyes causes burns similar to those caused by 60% to 70% nitric acid. Brief contact of the liquid with the skin or other tissues results in yellow staining; if the contact is more than momentary, a severe chemical burn will result. The N_2O_4 vapors that contact the skin are less harmful than liquid contact for a comparable period of time. If splashed in the eyes, N_2O_4 can cause blindness. Taken internally, the burn can be sudden and severe, resulting in death."
>
> "Because of its toxic effects, inhalation of N_2O_4 vapors is normally the most serious hazard in the handling operations. The M.A.C.* of this vapor is expressed as five parts of NO_2 per one million parts of air (2.5 ppm as N_2O_4)."
>
> "Emergency tolerance limits (Table G-I) for brief exposure of man to NO_2 have recently been set by the National Academy of Sciences, National Research Council Committee on Toxicology, at the request of the USAF."

* See Footnote on following page.

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Table G-I

EMERGENCY TOLERANCE LIMITS FOR BRIEF EXPOSURE

OF MAN TO NO_2

Time (Min)	Limits - Parts Per Million
5	35
15	25
30	20
60	10

"Small and large quantities of N_2O_4 can be vented slowly out-of-doors through elevated stacks. Rocketdyne uses a 50-foot stack from 15,000 gallon tanks for venting when atmospheric conditions are favorable. The Nitrogen Division of Allied Chemical Corporation indicates that quantities of N_2O_4 can be drained or pumped into a pond where the N_2O_4 can be neutralized with soda ash, or allowed to boil off, provided that the area is not populated. Neutralization should take place prior to dumping into a waterway. Because water is only slightly soluble in N_2O_4, and N_2O_4 is heavier, this process is time-consuming; the N_2O_4 might remain at the bottom and slowly convert to nitric acid. In addition, large quantities of N_2O_4 may be disposed of by burning with a fuel such as kerosene. Rocketdyne also burns N_2O_4 near test stand locations with liquid petroleum gas."

G.2.1.2 Fuel Blend Health Hazards

The following summary of health hazards imposed by the LEM fuel has been extracted from the previously cited references.

"Since the fuel blend is a mixture of UDMH and N_2H_4, it is recommended as a safety precaution that the lower M.A.C.* value of 0.5 ppm (parts per million) for UDMH be used as the M.A.C. for the fuel blend. The M.A.C. for N_2H_4 is 1.0 ppm."

Emergency tolerance limits (Table G-II)for brief exposure of man to UDMH have recently been set by the National Academy of Sciences, National Research Council Committee on Toxicology.

* Maximum Allowable Concentration. These represent values to which man can be exposed for a normal working day, day after day, without adverse effects upon his health.

Table G-II

EMERGENCY TOLERANCE LIMITS FOR BRIEF EXPOSURE

OF MAN TO UDMH

Time (Min)	Limits - Parts Per Million
5	50
15	35
30	20
60	10

"Experience with human exposure to N_2H_4 and UDMH is limited, but cases of delayed and possibly cumulative conjunctivitis have been reported among men in plants manufacturing N_2H_4. These employees complained of nausea, dizziness, and headache. The occurrence of dermatitis also was reported."

"In sufficient amounts, UDMH is toxic by inhalation, ingestion, and skin contact producing several significant systemic effects. In addition, UDMH produces local irritating effects upon the eyes and the respiratory tract; UDMH has little or no local effect on the skin, but is readily absorbed into the body by this route."

"Leaks or spills of fuel blend should be dealt with only by personnel wearing adequate protective equipment. Dilution with minimum quantities of water, flushing down drains into catch basins, should be accomplished as soon as possible. Minimum quantities of water are recommended so that the diluted fuel eventually may be disposed of by burning."

"During testing at Bell Aerosystems, an undetected UDMH spill drained into a nearby waterway. Shortly thereafter, dead fish were seen floating on the surface of the water. State water pollution authorities attributed the dead fish to UDMH which eventually led to extensive testing by the Water Pollution Control Board and the U.S. Public Health Service. These tests revealed that one ppm of UDMH and/or N_2H_4 had an adverse effect upon fish (Reference G-4). Because of this, steps were taken at Bell to destroy UDMH and/or N_2H_4. Subsequently, calcium hypochlorite* was used for the chemical destruction of small quantities of UDMH and N_2H_4 prior to draining into a public waterway."

* Calcium Hypochlorite Needed: 1.6 lb/gal of solution containing 1% by weight N_2H_4; 0.8 lb/gal of solution containing 1% by weight UDMH.

"Because the fuel blend in water can have adverse effects on fish and animals, it should not be added deliberately to drainage ditches or ponds without first reducing it to safe limits by addition of chemicals such as calcium hypochlorite or hydrogen peroxide. Bulk quantities should be collected in suitable containers for burning."

"The Martin Company (Reference G-5) recommends that fuel concentrations in the range of 1% to 40% be burned in a furnace and fuel concentrations greater than 40% be burned in air."

G.2.2 Propellant Spill Problem

The toxic hazard problem hinges on whether unprotected people and/or wild life will be exposed to an unsafe concentration after an accidental spill. To establish this, both the initial amount of released material and the quantitative aspects of the dispersion mechanism must be known. Both these aspects will be discussed in the following paragraphs.

It is assumed that the minimum quantity of propellant to be used in tethered flight will be on the order of 1000 pounds, and the maximum about 10000 pounds. Thefirst figure represents the amount for a two minute flight with the vehicle in a "lightweight" configuration (i.e., with inert ascent propellant removed) and the latter figure corresponds to the maximum vehicle weight for the LLRF.

In determining the amount of toxic material that could be released, it will be assumed that the worst has happened, i.e., that all the N_2O_4 or all the N_2H_4/UDMH in the tanks has been spilled, and that this could occur at any time during the fueling, checkout or test operation.* For the propellant weight cited above and an oxidizer to fuel ratio of 1.6, the minimum quantities of oxidizer and fuel which must be disposed of are 615 and 385 pounds respectively, and the maximum quantities are 10 times these figures.

G.2.2.1 Oxidizer Spill

The basic approach to eliminating the toxic hazard of an oxidizer spill is to reduce the local concentration below the maximum allowable level as rapidly as possible by disposal or dispersal. Reference G-2 suggests a source exposure time of 10 minutes as the maximum limit within which a spill must be contained.

* If fuel and oxidizer are spilled simultaneously, auto-ignition will occur and the fire hazard becomes critical.

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Containment can be effected by either encouraging rapid evaporation or by flushing the spill with large amounts of water (5:1 ratio) to reduce exposure to the atmosphere. Subsequent collection of the mixture is required. The 70° F oxidizer boiling point will insure rapid boil-off of spills at ambient temperatures above this level.

At nominal conditions of 56°F, 54% relative humidity, and no wind, Reference G-6 indicates an N_2O_4 evaporation rate of 1.06 pounds/hr/ft^2. This corresponds to a rate of .177#/ft^2 in 10 minutes. For an N_2O_4 density of 89.3#/ft^3 and a total spilled weight of 615 pounds, a 3480 sq. ft. spill area (67 foot diameter) is required.

If a flat paved surface is provided over the area under the LLRF (Reference G-7 indicates 178,000 sq. ft.), it is evident that such an arrangement would permit complete evaporation of any N_2O_4 charge of interest within a 10 minute period. As mentioned previously, spills at low temperatures would require the addition of water, hence a water wash system would also be needed.

To determine the safe diffusion distance for various weather conditions, Section XIII of Reference G-2 was used, together with the LRC map shown in Figure G-1. It was assumed that:

1. Safety in the event of a spill should not depend on a constant wind direction.

2. Traffic on Highway No. 172 could be diverted in an emergency.

3. Buildings such as the Morale Activities Building (Number 1222) and the two large wind tunnels (Numbers 1212A and B) must fall outside the potential danger area.

4. Based on 1, 2, and 3, the danger area radius should be 3000 feet.

5. The maximum safe N_2O_4 concentration for a single short exposure is 36.8 ppm. (Reference G-2).

The resulting variation in safe N_2O_4 charge and wind and temperature variations with altitude is shown in Figure G-2. Also indicated is the N_2O_4 charge range of interest for LTA-9 operation. It will be noted that the lapse rate has a dominating effect on the amount of N_2O_4 which can be spilled safely without endangering people within a 3000 foot distance. A normal lapse rate is about 3°F/1000 ft. and the figure shows that N_2O_4 charges well above the maximum value of interest (6150 pounds) can be safely spilled under any wind condition for this lapse rate. Hence, the frequency of temperature inversions is the dominating weather characteristic affecting safe testing operations. This information will be used later in this Appendix as an input in the evaluation of weather effects on testing frequency.

G.2.2.2 Fuel Blend Spill

Reference G-8 indicates that the fuel blend evaporation rate will be so low, virtually the entire spill must be controlled. This presents a critical problem since the water table at the LLRF is approximately 8 feet below the surface and the fuel blend is extremely toxic to sea life (see paragraph G.2.1.2). Thus, it is essential that no spill be allowed to seep into the ground.

The paved barrier needed to accelerate the evaporation of N_2O_4 (see paragraph G.2.2.1) would also supply the necessary protection from fuel blend contamination. Following a spill, the fuel would be washed into a collecting basin provided for this purpose. Since the disposal of large amounts of fuel blend would normally not be required unless an emergency occurred, it is felt that the most convenient disposal method for LRC would be to collect the spill and ship it to a commercial facility specifically designed for this purpose.

G.2.3 Fire and Explosion Hazard

There is apparently some disagreement between authoritative references on whether blast damage can occur following a simultaneous spill of both the oxidizer and fuel blend.

Reference G-9 presents the following summary of the propellant explosion hazard:

> "One of the advantages of N_2O_4/Aerozine 50 (the LEM fuel blend) and of other hypergolic systems, whether storable or cryogenic, is that they do not form detonable mixtures. It is well known, for instance, that liquid oxygen and kerosene (a non-hypergolic pair) form mixtures which have the properties of high explosives. In fact, the term LOX is applied to a commercial explosive of this type that is used for blasting. On the other hand, when N_2O_4 and Aerozline 50 contact each other, their instant interaction produces gaseous reaction products that tend to prevent further mixing of the liquids. Because the gases produced by instantaneous combustion tend to push the liquids apart, splash plates and deflectors are required in the combustion chamber with certain types of injectors to force the liquid streams together. With spills, where the liquids are unconfined, gross mixing cannot occur. Therefore, the possibilities of a detonation and the wide-spread damage that is associated with shock waves arising from detonations are absent."

> "Although the fires produced by the simultaneous spillage of large amounts of N_2O_4 and Aerozine 50 can be destructive

in the immediate vicinity, they can be fought by conventional fire-fighting methods, if the required amounts of extinguishing agents and equipment for their application are available."

For comparison purposes with the above text, the following material from Reference G-3 is also presented:

"Rocketdyne---has ----- conducted two large-scale mixing spills in an open tray with Titan II propellants*. For the first test, a water deluge followed the simultaneous spill of 300 pounds of 50/50 fuel blend and 1300 pounds of N_2O_4. The water helped to prevent or mitigate the blast hazard by reducing the amount of fuel vapor present in the air above the fuel surface. Also, this spill showed no recorded overpressures, although several weak explosions were audible. Water accelerated the boil-off of N_2O_4 and, thereby, increased the toxicity hazard. In the second test, when 500 pounds of 50/50 fuel blend and 800 pounds of N_2O_4 were simultaneously spilled in an open tray, the resultant blast effects were greater than corresponding tests with 200 pounds of fuel and 100 pounds of N_2O_4. This indicated more efficient propellant mixing with the larger propellant quantity."

" The Atlantic Research Corporation reported two explosions when laboratory quantities of propellants were mixed. When 0.006 pound (2.7 grams) of 50/50 fuel blend was spilled onto 0.033 pound (15 grams) of N_2O_4, one explosion occurred during five tests; however, when 0.10 pound (4.5 grams) of N_2O_4 was spilled onto 0.006 pound of fuel blend, an explosion occurred for the one test. No pressure measurements were reported for any of these tests since the primary purpose of this work was to study control of fires involving N_2H_4-type fuels with air and N_2O_4."

While a detonation in the classic sense is unlikely, blast damage in the immediate vicinity is a real possibility and vigorous fire is a certainty. Hence, facilities for operating personnel and equipment should be designed for both fire and explosion hazard.

G.2.4 <u>Additions to the LLRF Needed for LEM Operation</u>

In the previous paragraphs, the major propellant hazard problems associated with LEM operation in a gantry tethered facility were discussed. The facility requirements included:

* These are the LEM propellants also.

1. A non-reactive pavement covering the flight area.

2. Water flush equipment for the flight area.

3. Provision for collecting and/or draining mixtures of fuel blend and water into containers.

4. Fire and explosion resistant structures in the immediate test area.

It should be noted that the LEM propellants can be stored in the containers in which they are shipped providing the precautions equivalent to the above are maintained and the recommended temperature control and pressure relief procedures are carried out.

In addition to the above items, it is necessary to provide a local landing area in which the descent engine can be operated immediately above the surface for several seconds at a time.

G.3 WEATHER EFFECTS ON TEST SCHEDULING

In order to determine the extent weather limitations at LRC and WSMR could effect testing operations, published weather information was reviewed in the light of three testing requirements:

1. Wind of 9 mph or less.

2. A lapse rate of $1^{\circ}F/1000$ ft or better at the surface.

3. No precipitation.

The wind limitation was based on the assumption that the aerodynamic moment should not exceed on the order of 25 per cent of the available control moment, and that the maximum gantry tether speeds will be based on the need to fill the low speed range not feasible for helicopter tether testing. The discussion in Appendix K indicates that the aforementioned control limit would occur at an air speed of 18 ft/sec and that the nominal gantry tether speed would be approximately 12 ft/sec. Assuming that wind parallel to the longitudinal track axis could be compensated for by choosing a down-wind flight direction, the critical wind condition would be in a direction at right angles to the track axis. Resolving the vectors, the maximum allowable cross wind would be 13.4 ft/sec (9 mph).

The lapse rate limit was based on figure G-2* which shows that,

* Although no firm decision regarding location of the tethered facility at WSMR has been made, a review of current WSMR planning indicates that the 3000-foot distance of figure G-2 could easily be provided.

for this value, the maximum N_2O_4 charge of interest could be spilled under 4.5 mph wind conditions. This is the average between no wind and the maximum acceptable wind, and is felt to be a judicious choice considering wind variability. The precipitation limit was based on the assumption that rain protection during pre-test and test operations would be an unacceptable compromise in testing efficiency.

The wind and precipitation data for LRC and WSMR are shown in figures G-4 and G-5. It can be seen in figure G-4 that at WSMR acceptable wind conditions prevail about 66 per cent of the time with calm conditions existing 28 per cent of the time. At LRC acceptable wind conditions prevail about 44 per cent of the time with 4-12 mph being the most frequent condition. Figure G-5 indicates that precipitation at WSMR is about 15 per cent of the LRC value. The WSMR value is low enough to suggest that precipitation would have little effect on test scheduling.

In order to obtain a more detailed indication of weather effects on LTA-9 operations, the National Weather Records Center was asked to review their records for a representative year and determine on what days a simultaneous combination of the three required conditions occurred during daylight hours. If it is then assumed that an LTA-9 would always be ready to test, the resulting daily weather information shows directly how weather would have affected operations. The results of the Weather Records Center survey are shown in Table G-3*.

It can be seen that during the first, second and fourth quarters, WSMR presented about 50 percent more acceptable testing days than LRC, or 126 out of a total of 202. During the third quarter test opportunities at both facilities were about 72 percent of a total of 67 days. During the first three quarters, the weather pattern at WSMR was such that it would seldom be necessary to wait more than one working day in order to test. In the fourth quarter, however, it would have been necessary on several occasions to wait several days at either facility.

On the basis of a full year of 269 working days, 175 were suitable for testing at WSMR and 131 were suitable for testing at LRC.

* On weekends, lapse rate soundings usually were not taken at WSMR and so it was assumed that neither facility could test then.

G.4 AN APPROACH TO A TETHERED FACILITY AT WSMR

In view of the safety and weather advantages offered by the WSMR test site, consideration has been given to the possibility of locating a tethered facility at WSMR. The advantages in scheduling and ground support equipment offered by such an approach have been cited in Sections 3 and 7 respectively.

As explained in Appendices D and K, the test objectives requiring a large trajectory envelope can be obtained by using a helicopter tether. Hence, the gantry tether providing a maneuver envelope complementing the helicopter tether envelope would fulfill the LTA-9 test requirements.

Grumman has performed a preliminary analysis to determine the size of such a facility indicating that an envelope less than that provided by the LLRF may be adequate. In view of the existence of a gantry and servo design meeting the LTA-9 needs (see Appendix D) it is suggested that a duplicate of the LLRF gantry could be installed at WSMR and that the possibility of using only one LLRF bay be investigated further.

It is further suggested that, rather than building duplicates of the LLRF Bridge Crane and Dolly, the original LLRF Crane and Dolly could be transported to WSMR for use during the LTA-9 program. In order to minimize the problems usually associated with the transportation and checkout of complicated equipment, it is also suggested that the LLRF components be air-lifted directly from LRC to WSMR. This would minimize the incremental down time for the LLRF over the occupancy time that would be involved for LTA-9 operations at Langley.

Such an approach offers the following advantages:

1. Economy - No new tether design and analysis work is required and the only new construction would be a duplication of the LRC gantry structure.

2. Minimum Development Risk - All the lessons learned in developing the LLRF and testing the Langley Research Vehicle would be directly applicable to the WSMR facility.

3. Flexibility - Additional gantry bays could later be added if the test period indicates that operational experience on such a facility is shown to be desirable.

It is recommended that the above merits be considered by NASA when reviewing the overall plans concerning the combination of a tethered facility for limited envelope testing and a helicopter tether for wide flight envelope testing and flight experience.

APPENDIX G. REFERENCES

G-1 MSC letter SLM-63-40, dated 23 April 1963, and enclosure, "Minutes of Meeting, GAEC Presentation on LTA-9 Program Summary".

G-2 Air Force Technical Manual (T.O. 11C-1-6) "General Safety Precautions for Missile Liquid Propellants", change date 27 November 1961.

G-3 "Titan II Storable Propellant Handbook", Bell Aerosystems Company, March, 1962.

G-4 Water Pollution Control Board, New York State, Henderson,C.

G-5 Drake, R.W. "Martin - Denver Operation Plan for the Contamination and Disposal of Wastes from the Testing of the XSM-68B", the Martin Company.

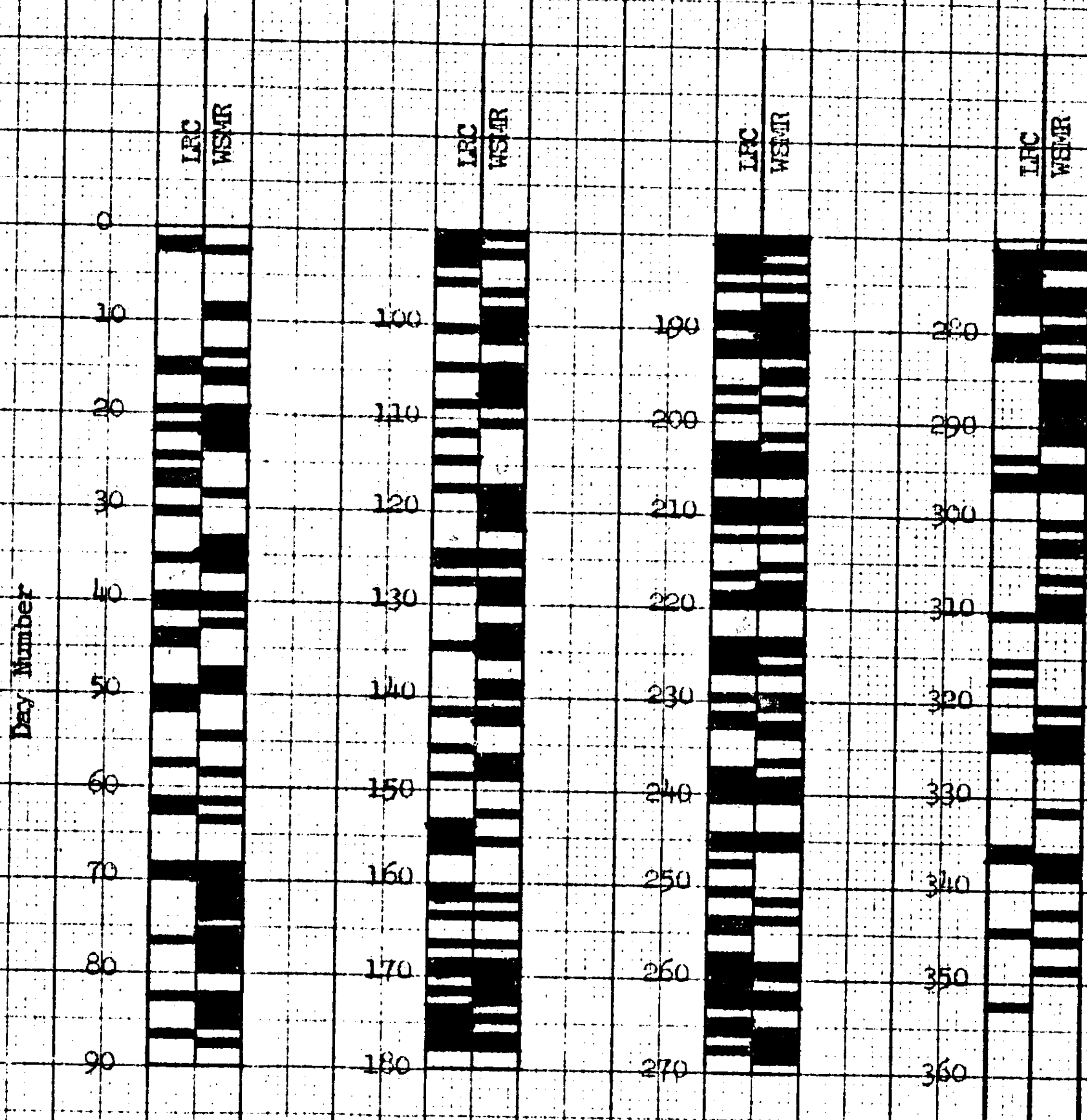
G-6 Ackerman, H., Staff Safety Officer, Missile and Space Systems Safety Branch, Safety Division, Officer of the Inspector General, Enclosure 2 of letter to GAEC dated 1 October 1962.

G-7 LRC & Jackson and Moreland Drawing No. LD-501755, "Lunar Landing Research Facility, General Arrangement - Launcher".

G-8 "Research on Hazard Classification of New Liquid Rocket Propellants, Final Report, Volume I", USAF Report AF/SSD/TR-61-40 (Rocketdyne No. R-3217) dated October 1961.

G-9 "Storable Liquid Propellants - Nitrogen Tetroxide/Aerozine 50", Aerojet-General Corporation Report No. LRP 198 - Second Edition, dated June,1962.

Table C-3 Acceptable Test Weather at LRC and WSMR During One Year



▬ Indicates combination of:

Daylight

Winds under 9 mph

Lapse rate over 1°F/1000 ft.

No precipitation

Missing record days (usually holidays and weekends) are shown as not acceptable at both facilities.

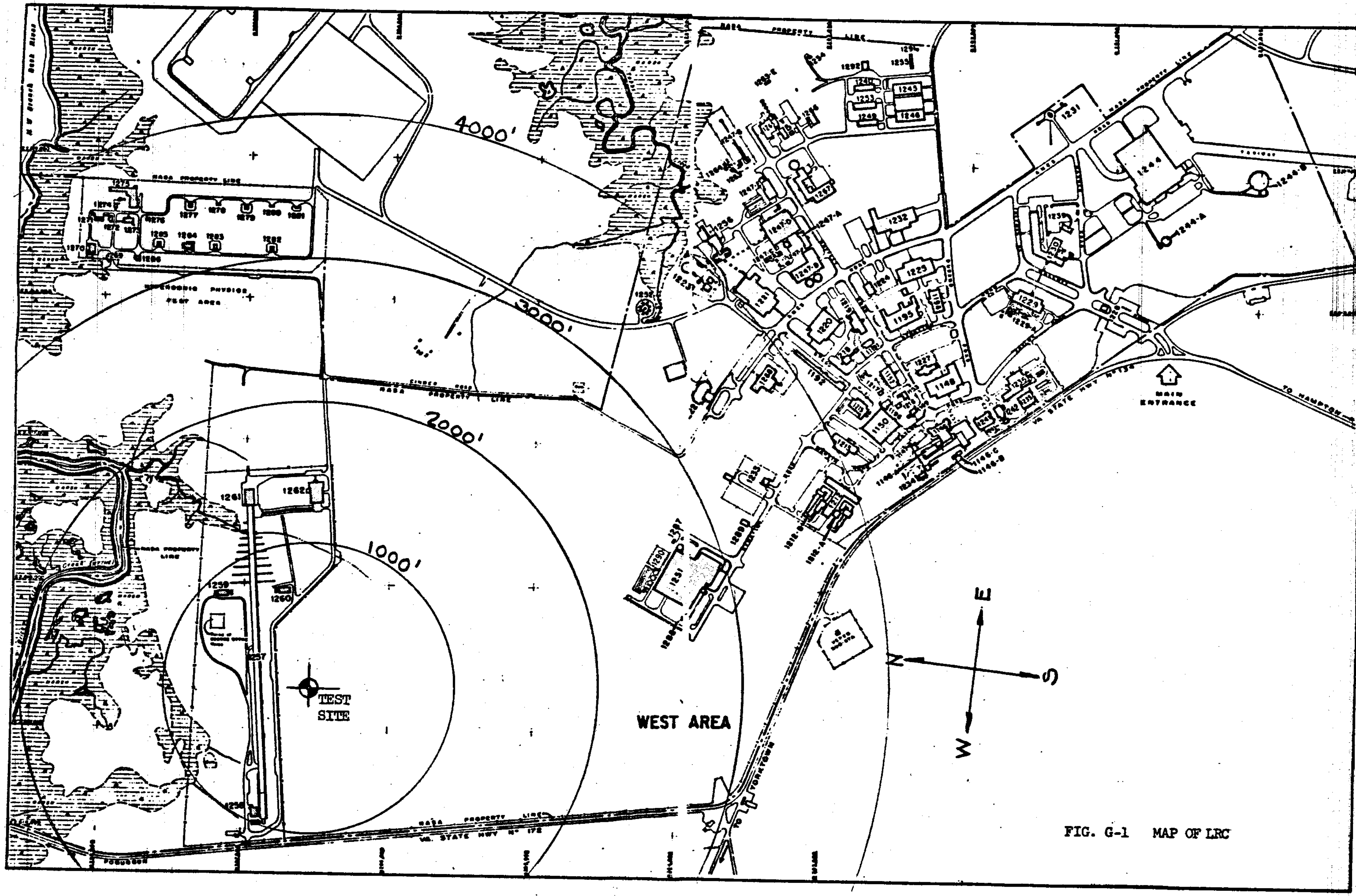


FIG. G-1 MAP OF LRC

FIG. G-2

OFFICIAL NUMBERS AND FORMER DESIGNATIONS OF LANGLEY RESEARCH CENTER BUILDINGS

EAST AREA

Building No.	Former Designation
587	Administration Building
580	Atmospheric Wind Tunnel
582	East Compressor Building
582-A	Low-Turbulence Pressure Tunnel
581	Thornell Avenue Substation
585	22-Inch Transonic Tunnel
640	8-Foot Transonic Pressure Tunnel
586	Service Building
643	Full-Scale Tunnel
720	Tank No. 1
720-B	Tank No. 2
720-A	Dynamic Model Shop
583-A	Maintenance Building
583	Transonic Blowdown Tunnel
641	8-Foot Transonic Tunnel
642	Back River Substation
645	20-Foot Free-Spinning Tunnel
646	Dynamic Tunnels Building
644	Free-Flight Tunne'
647	East Shop
648	Transonic Dynamics Tunnel
650	Mathis Road Substation
584	Utility Building
537-R	East Flight Research Laboratory

WEST AREA

Building No.	Former Designation
1146	16-Foot Transonic Tunnel
1147	Taylor Road Substation
1148	Structures Research Laboratory
1149	Stability Tunnel
1150	West Model Shop
1151	Cooling Tower
1152	Power Plant
1153	Metal Finishing Shop
1191	9-Inch Supersonic Tunnel
1192	Impact Basin
1194	West Shop
1195	Warehouse
1196	Foundry
1212	7- by 10-Foot Tunnels Laboratory
1212-A	300-MPH 7- by 10-Foot Tunnel
1212-B	High-Speed 7- by 10-Foot Tunnel
1213	West Cafeteria
1215	West Heating Plant
1217	Electrical Storage Building
1218	Gust Tunnel
1219	Langley Research Center Headquarters
1220	Aircraft Loads Calibration Laboratory
1221	Internal Aerodynamics Laboratory
1222	Morale Activities Building
1223	Sewage Disposal Plant
1224	Lumber Storage Shed
1225	West Machine Shop
1227	Temporary Building No. 1
1228	West Area Pass Office
1229	Physical Research Laboratory
1229-A	Flutter Tunnel
1230	Instrument Research Laboratory
1231	Helicopter Apparatus
1232	Pilotless Aircraft Research Laboratory and Fabrication Shop
1233	Stratton Road Substation

WEST AREA (Continued)

Building No.	Former Designation
1235	Frequency Converter Building
1236	4- by 4-Foot Supersonic Pressure Tunnel
1239	Warner Road Substation
1240	Temporary Warehouse No. 3
1241	Drive Control Building
1242	Propeller Static Test Stand
1244	Flight Research Laboratory
1247-A	Water Tank No. 2
1247-B	Temporary Warehouse No. 1
1247-C	Temporary Warehouse No. 2
1247-D	Gas Dynamics Laboratory Center
1247-E	Gas Dynamics Laboratory West Wing
1247-F	Gas Dynamics Laboratory Cooling Tower
1247-G	Gas Dynamics Laboratory East Wing
1249	Gas Dynamics Compressor Building
1251	Ames Road Substation
1252	High-Pressure Shock Tube
1253	Temporary Warehouse No. 4
1254	Unitary Plan Wind Tunnel
1255	Water Tank No. 1
1256	Temporary Warehouse No. 5
1257	Ammunition Storage
1258	Temporary Warehouse No. 6
	9- by 6-Foot Thermal Structures Tunnel
	Landing Loads Track
	Landing Loads Track Compressor Building
1259	North Arresting Gear Housing
1260	South Arresting Gear Housing
1261	Landing Loads Track Shop
1262	High-Speed Hydrodynamics Office and Shop
1263	Ceramic-Heated Jet (Pilot Model)
1264	High-Temperature Mach 7 Jet (Pilot Model)
1265	8-Foot High-Temperature Structures Tunnel
1266	Moffett Road Substation
1267	High-Temperature Materials Laboratory
1268	Data Reduction Building
1269	Gate House (Hypersonic Physics Test Area)
1270	Rocket Propellant Test Unit, HPTA
1271	Open Shed, HPTA
1272	Heating Plant, HPTA
1273	Operations Center, HPTA
1274	Ceramic-Heated Mach 15 Jet, HPTA
1275	Impact and Projectile Test Unit, HPTA
1276	Igniter Assembly Building, HPTA
1277	Storage A, HPTA
1278	Storage B, HPTA
1279	Storage C, HPTA
1280	Storage D, HPTA
1281	Storage E, HPTA
1282	Storage F, HPTA
1283	Storage G, HPTA
1284	Rocket Propellant Processing Building, HPTA
1285	Storage H, HPTA
1286	Rocket Assembly and Propellant Alteration Building
1287	41-Foot Vacuum Sphere Shop
1288	Solar-Energy Collector
1289	Temporary Shelter
1290	Substation - UPWT
1291	Pump Station
1292	Vehicle Service Building
1293	Dynamics Research Laboratory

EFFECT OF LAPSE RATE & WIND ON SAFE N_2O_4 CHARGE

DISTANCE = 3000 FEET

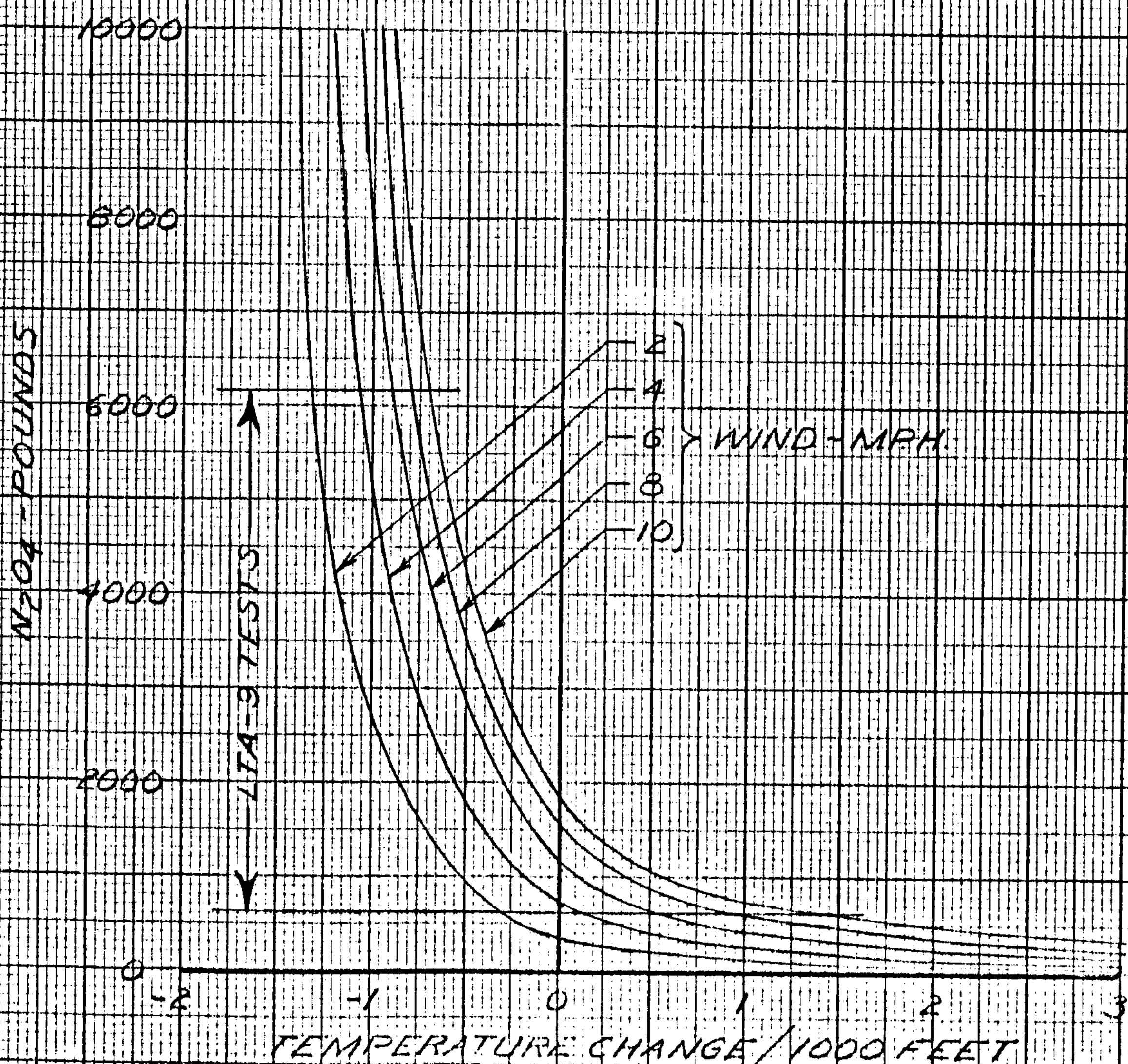


FIG. G-3

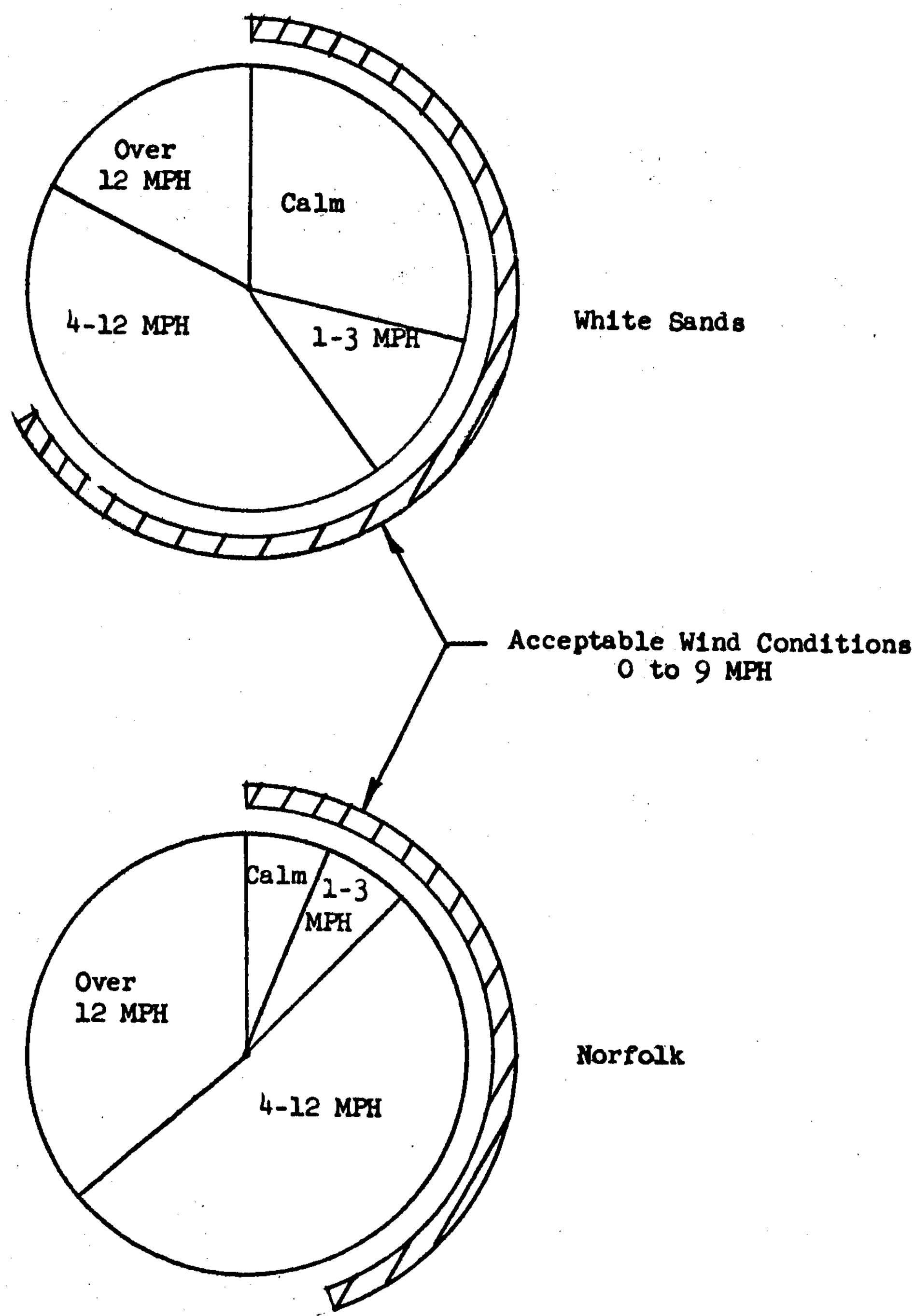


Figure G-4. Wind Velocity and Frequency at Norfolk, Va. (LRC) and White Sands, N.M. (WSMR)

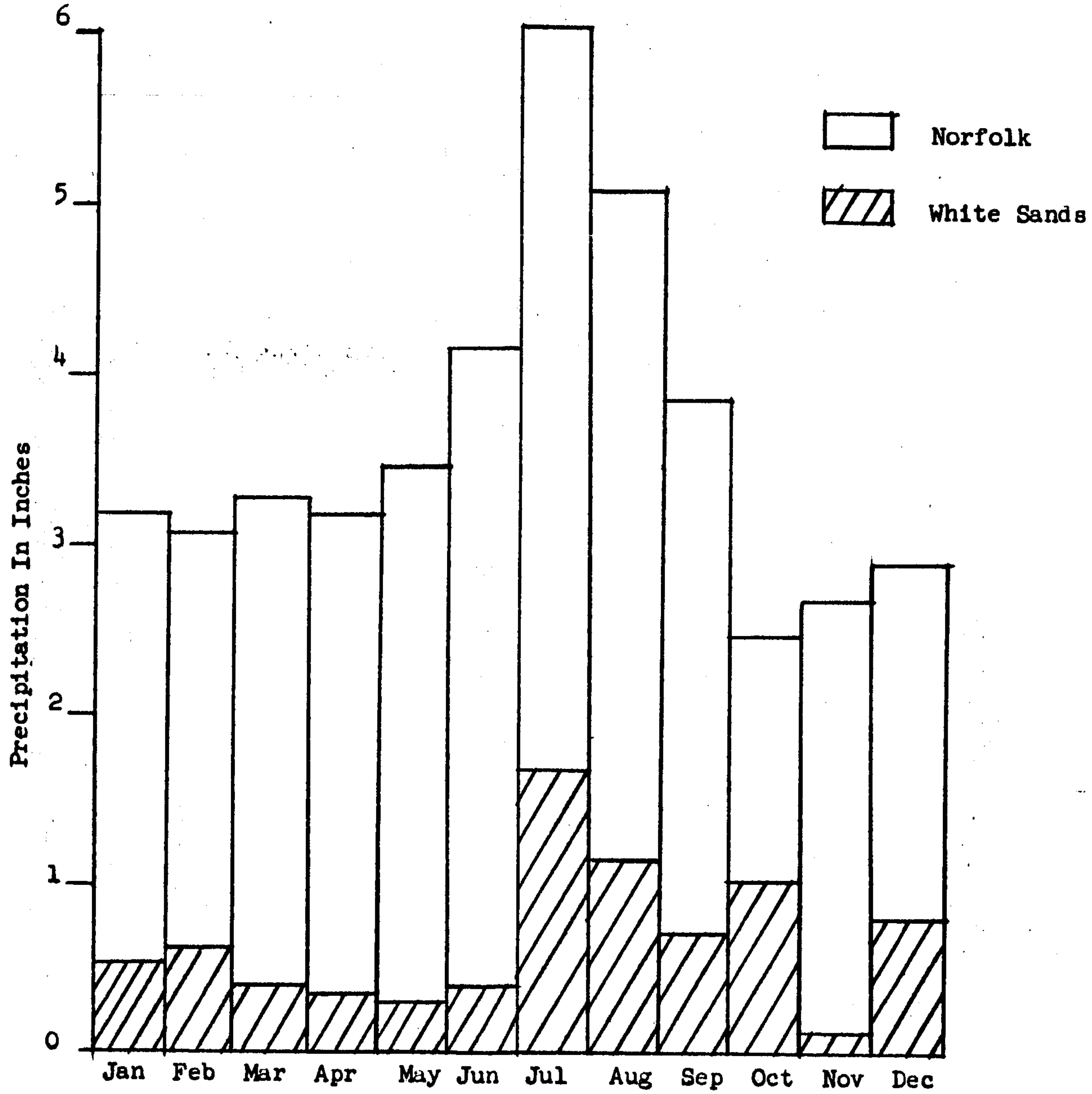


Figure G-5 Yearly Precipitation at Norfolk, Va. and White Sands, N. M.

APPENDIX H

FREE FLIGHT VERSION OF LTA-9

H.1 INTRODUCTION

This section describes the preliminary design effort directed toward determination of the minimum modification and usage of an all-rocket free-flight LTA-9 for atmospheric test/flight experience. Consideration was given to the extent of the modifications required to provide a usable and safe vehicle as well as the ability to perform the functions of dynamic testing and operational experience and training.

After establishing the basic modification required for free flight, a detailed preliminary design of this configuration was conducted. Concurrently, while the design effort continued, potential problem areas were investigated.

Among the major areas investigated were the handling qualities of a free flight vehicle under "Earth - g" conditions. The analytical appraisal of the characteristics indicated that the vehicle flying qualities would be different from those that would be experienced on LEM. Hence, a simulation program was implemented by modifying the Grumman 6°-of-freedom Lunar Landing Simulation for the proper LTA-9 conditions. The results of this simulation effort are described in Section H.2.3.

Another area where tests were conducted to supplement analysis was to determine the effects of operating this vehicle in close proximity to the ground. The results obtained from these tests as well as a brief review of previously conducted wind tunnel tests of the basic LEM configurations are discussed in Appendix I.

The present study has indicated that an off-loaded free flight LTA-9 configuration is unsatisfactory for several major reasons:

1. The degree of modification in order to sustain free flight compromises the test objectives.

2. Free flight time is severely limited, even with off-loading of unexercised equipment and using a helicopter to release the vehicle.

3. The flight envelope, even with an assisted take-off, is limited to altitudes below 500 feet.

4. The flight velocity/attitude relationship is non-LEM (i.e., non-lunar).

5. Maximum atmospheric thrust, on the order of 7000 lbs., is required for most of the trajectory.

6. The atmospheric ground effect is negative and causes unstable pitching moments.

7. The single engine, weight limited, short flight duration vehicle unduly compromises crew and vehicle safety.

The overall conclusions of this study are that a free flight-all-rocket LTA-9 does not satisfy its intended requirements. The key areas where this version falls short of providing the ability to perform its intended functions, of dynamic testing of LEM equipment and operational experience and training with a LEM-type vehicle, are summarized in the following sections.

H.2 VEHICLE DESCRIPTION

H.2.1 Basic Configuration

The free flight version of the LTA-9 consists of a basic LEM carrying those subsystems required for operational testing of the Flight Control System plus those components of the Navigation and Guidance System associated with the terminal descent maneuver. Additional subsystem components essential to the free flight operations are also installed. The major structural modifications involve the installation of one ejection seat and the replacement of the existing LEM landing gear with a work horse landing gear capable of sustaining repeated landings.

In this design no attempt was made to simulate lunar gravity. (i.e., no auxiliary lift devices were installed). Further, no environmental compensation system was incorporated to minimize the effects of aerodynamic forces, moments, and damping. From the LTA-9 Feasibility Study (Reference 8), it was felt that being a major modification item, the addition of a complex compensating system would jeopardize the early availability of this vehicle. Also, the development of a compensation system does not in itself add any direct contribution to insure the success of the LEM.

Figures H-1 and H-2 show the general arrangement of the ascent and descent stages of LEM as modified for the free flight vehicle.

To increase free flight duration, all subsystems and components not required or exercised during terminal descent are eliminated. This includes the entire ascent propulsion section, electrical power supply, fuel cells and reactant tankage, UHF communications, lunar scientific equipment, etc. With all unnecessary equipment removed, the vehicle can operate in the free flight mode for 90 seconds with an unbalanced c.g. and no reserve propellant. In order to bring the c.g. within the LEM limits, 200 pounds of ballast are required, which further reduces the flight duration to 82 seconds. The alternate solution of shifting the equipment aboard the LTA-9 to balance the vehicle was discarded because it contradicts the ground rule of a minimum modification vehicle.

The free flight performance (flight running time versus touchdown weight) is shown in Figure H-3. The curves show that the effect of thrust-to-weight ratio and variations in delivered specific impulse on flight duration is minor.

The figure shows that a vehicle with zero propellant and a touchdown weight of 4559 (including 200 pounds of ballast for maintaining c.g. location) yields 82 seconds of running time. Considering a 15 second propellant reserve, leaves a maximum useful free flight time of 67 seconds. Even if the vehicle is carried to its starting point by a helicopter and then released, the maximum operating height will be below 500 feet for a reasonable sink rate and deceleration time.

The vehicle is supported by the LEM Descent engine modified for atmospheric operation as described in Appendix B. Maximum thrust attainable for this engine is approximately 7000 pounds. Since the vehicle does not have any auxiliary lift devices, the engine will always operate near its maximum output and only limited throttling can be used. The vehicle uses batteries in lieu of fuel cells to reduce equipment weight. Appendix B discusses subsystem modifications required by the remaining LEM equipment. The following sections describe modifications unique to the free flight version LTA-9.

H.2.2 Modifications for Free Flight LTA-9

H.2.2.1 Ejection Seat

The operational hazards associated with a free flight vehicle that obtains its entire support from a single rocket engine are obvious. Since the vehicle does not rely on aerodynamic surfaces for support, trim or attitude control, any failure in the Propulsion or Flight Control System will result in loss of the vehicle. The use of a vehicle recovery parachute system is not practical due to excessive weight and altitude requirements (See Section 8-4, Reference 8).

Since free flight operation involves only a one-man crew, a single zero altitude-zero velocity Martin Baker A2 ejection seat is installed on the L.H. side or pilot's position within the fore and aft envelope of the crew compartment. This installation is shown in Figure H.4.

A tubular support is bolted to the bottom of the seat catapult and another support is attached to the top of the catapult.

Carry-through structure picks up these supports and distributes the seat loads into the crew compartment bulkhead and the structure aft of the crew compartment. The load is distributed through channels which are added to the existing structure.

A breakaway escape hatch is provided over the pilot providing sufficient ejection clearance. This hatch may be opened externally through the use of the two pin latches located in the inboard edge of the hatch. Existing structure must be removed in the area of the escape hatch and reinforcing structure added. Four channels are attached to the crew compartment outer structure and pick up the hatch hinge pins along the outboard edge.

To provide proper ejection clearance, it is necessary to relocate some displays in the crew compartment. There will be a slight positive pressure in the crew compartment and seals installed along the four sides of the escape hatch to prevent inflow of toxic rocket exhaust.

H.2.2.2 Workhorse Landing Gear

A workhorse landing gear was designed for repeated use in a one-g environment. A further benefit of this workhorse gear is a reduction in weight since the required tread is much smaller for LTA-9 than LEM for the same overturning moment. Installation of the landing gear is shown in Figure H-5.

The shock strut is a conventional air-oil aircraft type utilizing variable metering of hydraulic oil as the primary energy absorption medium rather than the crushable honeycomb used in LEM. An air spring is provided to prevent bottoming under static conditions and to provide automatic extension upon removal of external load. Primary components of the strut are the high strength steel inner cylinder which supports the variable diameter metering pin, and the aluminum outer cylinder which supports the fixed metering orifice and provides the strut attachment points to the landing gear support truss and the LTA-9 drag/side brace.

The design is based on the following criteria:

Max. Vehicle Gross Weight	7000#
Limit Vertical Velocity	10'/sec.
Limit Horizontal Velocity	5'/sec.
Touchdown Attitude to Horizontal	5°
Landing Surface	Prepared level hard surface.

A combination drag/side brace, designed to carry the loads produced by moments about the upper shock strut attachment point is composed of an aluminum alloy "A" frame. The two members will be bridged by a common fitting at the strut attachment to provide restraint for torsional moments about the strut centerline transmitted to the outer cylinder thru bearing friction.

A spherical contoured pad with a projected bearing area of 90 square inches designed to support landing loads on a 50 psi surface is provided in the event a landing would be required outside of the limits provided by the prepared landing surface. Repeated usage is enabled by use of a steel outer shell separated from an aluminum housing by a rubber or polyurethane shock absorbing pad.

Preliminary estimates of temperature gradient resulting from rocket exhaust effects on the gear at touchdown indicate that use of a castered wheel and tire combination would be unacceptable. Thermal insulation may also be required on the aluminum outer cylinder to minimize oil temperature variations and on the aluminum drag/side brace. The total estimated weight of the workhorse landing gear is 178 pounds.

H.2.3 Mass Properties

Due to the limited thrust capability of the descent engine when modified for atmospheric operation, all equipment and subsystems not essential to free flight are off-loaded. The following non-essentials are omitted from the LTA-9 free flight vehicle:

Descent engine, skirt and thermal shielding
Chart books and shades
PLSS
Radiation Dosimeter
Food & Water & Storage
Useable O_2 LiOH (ECS)
Water (ECS)
Scientific Equipment
Fuel Cells (ECS)
Ascent Propulsion System
Fuel & Oxidizer (All Ascent & Partial Descent)
Fuel & Oxidizer (Partial RCS)
Erectable Antenna
Spares
Spare Suit(1), Crew (1)
Seats & Restraints (2)
Landing & Running Lights
Super Critical O_2 tank
IFTS & Clock
Tape Recorder & Reels
RCS Nozzle Skirts
Intercom
Lunar Stay Antenna & Steerable Dish
Earth Sensor & Drive
Rendezvous Radar
Meteoroid Shielding & Thermal Insulation
Separation System
N&G Backup

Items added to LTA-9 Free Flight include the following:

Ejection seat and escape hatch
Freon (ECS)
Batteries
Workhorse Landing Gear
Modified Descent Engine
Thermal Protection for Descent Stage Engine Well

The weight balance and inertial characteristics for this version were derived from the mass properties of the LEM as of 15 June 1963.

Based on the above list of omitted and added equipments, a zero propellant weight of 4359 pounds is attainable. Table H-1 compares the mass and inertial characteristics of the free-flight LTA-9 with those of LEM during the hover and landing phase of the mission.

TABLE H-1

VEHICLE	PHASE	WEIGHT (#)	ARM (IN.)			INERTIAS (SLUG-FT^2)		
		W	X	Y	Z	Ix	Iy	Iz
LEM	Hover Touchdown	12398.9 11408.7	213.1 219.4	-0.3 -0.4	-1.1 -1.2	8508 7823	10289 8621	11299 9759
LTA-9 Free Flight	Hover Touchdown	7000 4359	184.3 205.5	-2.1 -3.3	0.7 1.2	5702 3922	6988 4612	5771 3660

Due to the weight reduction effected by the removal of non-exercised equipment, the inertias about all three axis are considerably below those of LEM. Also, there is a three-inch shift in the c.g. location on the Y-axis.

Table H-2 compares the relative angular acceleration capability (i.e., control power) of LEM and the free flight LTA-9 about all three axes from the hover and touchdown conditions. Handling differences arise from both the difference in vehicle mass properties and the lower RCS thrust available for atmospheric operation (57.5 lbs.). The larger spread in control power exhibited by LTA-9 is attributable to the larger percentage change in mass properties due to propellant burn-off.

TABLE H-2

VEHICLE	PHASE	α_x (°/sec^2)	α_y (°/sec^2)	α_z (°/sec^2)
LEM	HOVER TOUCHDOWN	6.87 7.50	6.07 7.27	5.56 6.42
LTA-9 FREE FLIGHT	HOVER TOUCHDOWN	5.90 8.59	5.16 7.85	6.24 9.91

		X	Y	Z
Percentage difference of angular acc. control capabilities of the LTA-9 with respect to LEM	HOVER	-14	-15	+12
	TOUCHDOWN	+15	+ 8	+54

H.3 PROBLEM AREAS

H.3.1 Ground Effects

Operating LTA-9 in the atmosphere in close proximity to the ground produces a strong negative force field. Model tests indicate that the engine mass flow causes a pressure field on the base of the vehicle. This field produces both a negative force (suction) and also an unstable moment on the vehicle in the presence of vehicle tilt.

The ground effect tests discussed in Appendix I indicate that for the free flight LTA-9, there would be a suction force between the ground and the LTA-9 on the order of 2500 pounds at touchdown to 800 pounds at a height of 50 inches. In this height range, a tilting moment of as much as 14000 ft./lbs. can develop if the LTA-9 is tilted 10 degrees.

It would be possible to alleviate the ground effect problems just discussed by limiting landings to a facility specifically designed for such purposes. This might consist of a grating elevated from the surface to permit the exhaust gases to flow through. The landing facility would have to be of large size, however, to avoid compromising operational usage and safety. Such an installation would be expensive in view of the need to accommodate the high rocket exhaust temperatures and velocities.

H.3.2 Balance Problem

The mass properties described in Section H.2.3 show that removal of unexercised equipment causes a measurable shift in c.g. position. This is particularly severe about the pitch or Y-axis causing an unbalanced moment of about 14,000 in-lbs. While this unbalance may be compensated through repositioning of the operational subsystem components, a more practical solution is to add 200 pounds of ballast 72 inches outboard on the right (+Y) side of the vehicle.

H.3.3 Handling Characteristics

Operating in a one-g environment in addition to the changes in vehicle control power suggests that the piloting tasks and handling characteristics between LEM and the free flight LTA-9 will be very different. In order to gain further insight into these problems, the Grumman Phase A Lunar Landing Simulator of the LEM was modified to simulate the all-rocket LTA-9. The specific goals were to define the piloting problems and handling characteristics associated with LTA-9 system test maneuvers and to determine the value of LTA-9 for LEM crew operational experience.

Sufficient items were removed from the basic simulation LEM configuration to achieve a zero fuel weight of 5092 pounds, permitting 63 seconds of hover duration for an initial thrust/weight ratio of 1.0 and a 7000 pound thrust descent engine.

Review of test requirements and the LTA-9 operating limitations indicated that the following three maneuvers would exploit the major portion of the free flight LTA-9 test potential and provide reasonable basis for evaluation of LTA-9 utility for crew operational experience.

1) Release from tether, vertical descent and landing. This was the simplest maneuver. No translation was required and translation velocity stayed within landing tolerances as long as attitude control was tight. The principal task was height control and attitude control. It provided relatively little test information but represented the minimum practical flight duration.

2) Release from tether followed by one or more quick start and stops, then a landing - This maneuver provided significant exercising of the FCS system within a very limited (perhaps 45 seconds) flight duration. The quick start and stop technique permitted large tilt angle excursions while avoiding translation velocities exceeding aerodynamic limitations.

3) Reduced height and range LEM trajectories - Assuming that the LTA-9 was carried to altitude by a helicopter, it appeared feasible to fly the LTA-9 down from hover at a range and altitude of 500 feet from the landing site within 60 seconds. This represents a shortened version of the mission hover and touchdown phase and a valid maneuver for crew operational experience as well as for test of LEM systems.

Three qualified airplane pilots were used as subjects in the tests. The results can be summarized as follows:

1) For a given error in steady hover tilt attitude, the LTA-9 traveled six times further than the LEM because of the increased gravity on earth. However, in the attitude command mode, the pilot could stabilize the vehicle with the descent engine in the exact vertical position merely by releasing the hand

controller, thus it was easy to avoid tilt errors that would generate unwanted horizontal motions.

In the rate command mode there was no built-in tendency to null with the descent engine vertical, and with the great increase in horizontal translation sensitivity to tilt, greater concentration was needed to achieve acceptable landings.

In the direct control mode it was very difficult to hold an exact attitude position in either the LEM or the LTA-9. Hence, when flying the LTA-9 in this mode, the attitude errors usually generated unacceptably large horizontal motions in spite of the pilot's best efforts to control them.

2) The 1/6 g effect on tilt/translation coupling made some tasks easier and others more difficult compared to LTA-9. It was more difficult to fly LEM than LTA-9 down from a range and altitude of 500 ft. within 60 seconds. This is because the thrust reduction needed to initiate descent reduced horizontal translation capability and made the 500 ft. range difficult to achieve. The LTA-9 flights from a 500 ft. range and altitude were easy to accomplish in 60 seconds because the throttle reduction needed for descent still left a sizable thrust vector for horizontal acceleration and deceleration. It was considerably more difficult to keep the LTA-9 within the ± 5 ft. per sec. horizontal velocity landing gear tolerance, particularly in the direct control mode.

3) Even at the reduced gross weight, fuel burn-off rate was so high (about 30 lbs. per second) that unanticipated climb rates developed regularly on the LTA-9.

4) While at the end of the flight vertical accelerations well above one-g were available, it was necessary to start the flights at a thrust/weight ratio close to 1 in order to obtain acceptable flight durations. Hence, during early portions of the flights, landings were more difficult because the pilot could easily develop large descent rates so close to the ground that he did not have enough thrust margin to cancel them.

5) The use of the modified visual display system which presented familiar visual perspective cues, provided a distinct effect on LTA-9 flight technique except at the actual touchdown when display resolution degraded. Pilots found that visual flight techniques were easy to use under these conditions (and sometimes preferable), whereas there had usually been a preference for the instrument flight techniques when the lunar terrain display was presented.

The simulation study discussed above did not include aerodynamic effects such as ground effect and aerodynamic forces and moments. Grumman has carried out some special tests to evaluate these effects and the results have a profound effect on the anticipated LTA-9 handling qualities. The negative ground effect gives the LTA-9 a highly unstable altitude characteristic for which the pilot must compensate with continuous throttle adjustments during a touchdown.

The destabilizing tilting moments associated with the ground effects would provide extraneous inputs into the FCS during attitude or rate command mode operation, which could also affect the descent engine gimbal drive system. During direct mode operation, the pilot would have to anticipate the changing tilting moment gradient with altitude during landing as well as perform the challenging task of direct mode control.

H.3.4 Suitability for Systems Test of FCS

This section discusses the suitability of using a free-flight LTA-9 to evaluate and test the integrated Flight Control System. Since the performance of the FCS is strongly dependent upon the dynamic inputs and response characteristics of the vehicle, an ideal free flight vehicle for testing of the integrated flight control system should exhibit the following characteristics:

1. The handling qualities should simulate LEM handling qualities in the lunar environment.

2. Flight duration and range should be sufficient to permit testing of automatic descent modes with guidance system inputs.

3. Aerodynamic effects should not introduce spurious non-LEM forces or moments.

4. LEM systems and hardware should be used to the maximum extent possible.

5. The test vehicle responses to commanded inputs, by pilots or automatic mode, should closely simulate LEM behavior.

These criteria are not met by an all-rocket LTA-9 because:

* The free flight LTA-9 handling qualities with a torque to inertia ratio different from LEM will not be similar to LEM. The translational acceleration due to horizontal components of descent engine thrust with vehicle tilt will be six times higher than LEM since the descent engine thrust must support the vehicle weight in a one-g environment.

* In order to suppress the influence of aerodynamic effects, test vehicle velocity will be limited to approximately 20 ft./sec.

The difference between the horizontal translation characteristics of a free flight LTA-9 and those of a lunar LEM can be illustrated as follows:

For the free flight LTA-9, the translational acceleration is g sin Θ, where Θ is the angle of vehicle tilt from vertical. For LEM, translation acceleration = $\frac{g \sin \Theta}{6}$.

If Θ is assumed to be a maximum of 30° corresponding to a reasonable limit during the LEM touchdown maneuver, the resultant accelerations are:

Free Flight LTA-9 - 16.1 ft/sec^2
LEM Flight - 2.7 ft/sec^2

The time to reach 20 ft/sec velocity is, for free flight $\frac{20}{16.1} = 1.24$ sec., and for LEM flight, $\frac{20}{2.7} = 7.4$ sec.

Distance covered in reaching a velocity of 20 ft/sec., is:

$$\text{Free Flight} \quad - \quad \frac{at^2}{2} = \frac{16.1 \times 1.24^2}{2} = 12.4 \text{ ft.}$$

$$\text{LEM Flight} \quad - \quad \frac{2.7 \times 7.4^2}{2} = 74 \text{ ft.}$$

The values above illustrate the significant differences in the translational characteristics of the free flight LTA-9 as compared to LEM (or the tethered vehicle with lunar gravity simulation).

Any attempt to correct the translational characteristics by modifying gains and electronic circuitry will degrade the central system as far as similarity to LEM is concerned. Nothing can be done to affect the fundamental relationship between tilt angle and translational acceleration. The response of the vehicle to commanded attitude change inputs could be slowed down to the point that translation distance as a function of time commands would approach LEM characteristics. However, any such "doctoring" of the system would produce other dissimilarities between LTA-9 and LEM performance characteristics. Also, the objective is to test an integrated LEM flight control system. When systems are "doctored" and test results show trouble later, the question arises as to what is causing the trouble, the basic system, or the "doctoring".

H.3.5 Suitability for Operational Experience

In order to determine the usefulness of the free flight LTA-9 to obtain operational experience, it is worth while to establish how various aspects of this LTA-9 operation differ in magnitude from LEM operation and what aspects are completely foreign to LEM operation.

In previous portions of this report, it was established that the Free Flight LTA-9 operation differs from LEM operation in the following respects:

1) It is normally more difficult to keep the LTA-9 within the landing horizontal velocity tolerance, because the same vehicle tilt provided 6 times more acceleration on earth.

2) It is easier to accomplish simultaneous range and altitude changes, again because of the difference in thrust required to hover. For the above reason tilt angles on the LEM would also be about six times larger than on the LTA-9.

3) There would be a strong negative ground effect involving both vertical forces and destabilizing tilting moments during LTA-9 landings which would be absent on the moon.

4) The climb rate of change due to fuel burn-off would be a problem on the LTA-9 while it would be of negligible importance on the LEM.

5) Descent engine mechanical vibration level would be about 1.5 times higher on the LTA-9 than on the LEM because the hover thrust is 5000-7000 pounds for LTA-9 as compared with 2000 pounds for LEM.

It is apparent from the above discussion that the free-flight LTA-9 handling characteristics will differ markedly from those of the LEM. GAEC has concluded that this approach is inferior to tethered flight from the standpoint of affording operational flight experience to LEM crews.

H.3.6 Pilot and Vehicle Safety Aspects

In previous paragraphs describing the free flight all-rocket LTA-9, it was pointed out that a zero-zero ejection seat would be provided and that the descent engine would be requalified for manual flight in the atmospheric operation configuration.

There remain, however, several aspects of this LTA-9 operation which seriously compromise the crew and vehicle safety while not necessarily reflecting the safety of the actual lunar mission. These are listed on the next page.

1. On the lunar mission a descent engine failure could be followed by staging and return to the Command Module on the ascent engine. On the free flight LTA-9 descent engine failure must be followed by crew ejection.

2. The adverse ground effect presents a safety problem during landing that is absent on the LEM.

3. The limited flight duration exerts a constraint on pilot maneuvering and leaves little time for consideration in the event of an incipient emergency.

4. If the LTA-9 is carried to altitude for the longer flights with a helicopter, there would be a conflict between installation of the zero-zero ejection seat needed for atmospheric free flight and the safety line approach recommended for helicopter tether operation.

5. Weight limitations preclude installation of a second pilot and seat. Hence, each pilot must checkout in the free flight LTA-9 with only that instruction and/or background which can be gained from special LTA-9 simulators.

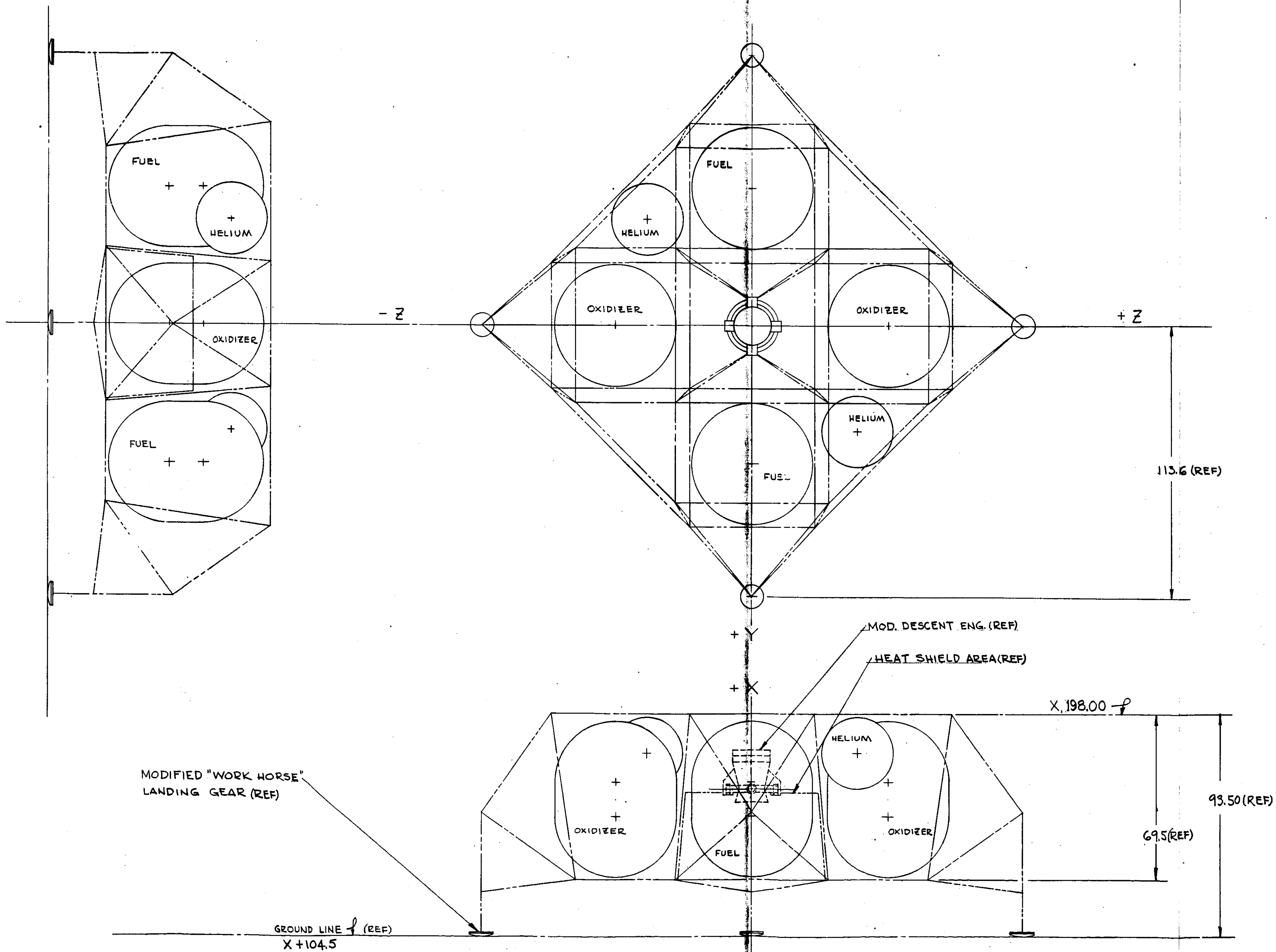


Fig. H-1

TANK AND EQUIPMENT ARRANGEMENT
LTA-9 FREE FLIGHT DESCENT STAGE

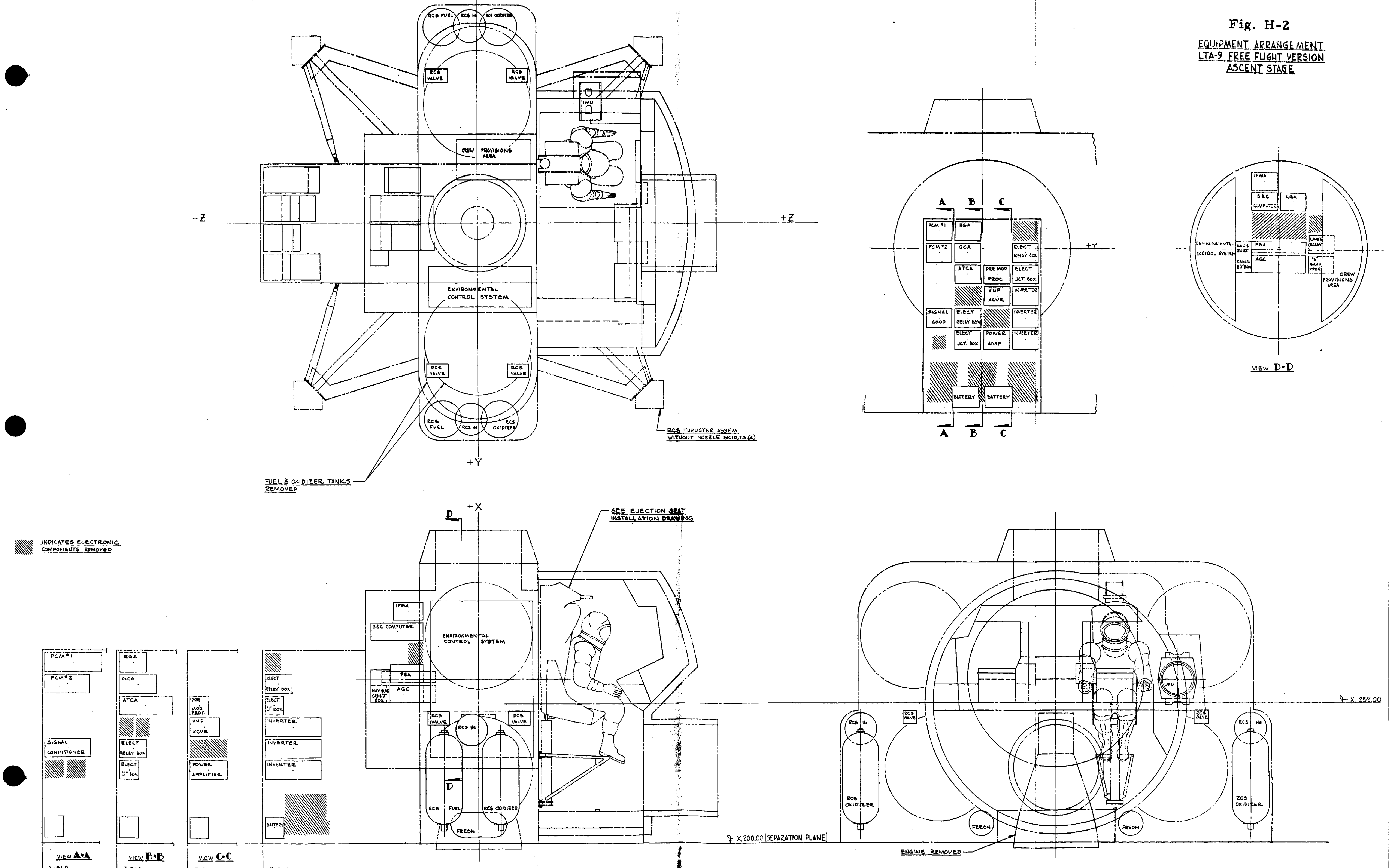


Fig. H-2

EQUIPMENT ARRANGEMENT
LTA-9 FREE FLIGHT VERSION
ASCENT STAGE

ALL-ROCKET LTA-9 PERFORMANCE

FREE FLIGHT MISSION

FLIGHT DURATION ENVELOPE

NOTES:

ENGINE THRUST / T/W = 6500 & 7000 lbs

I_{sp} = 190 & 210 lb/lb/sec

RCS PROPELLANT INCLUDED IN ZERO PROPELLANT WT

CURVE IDENTIFICATION IS SELF-EVIDENT

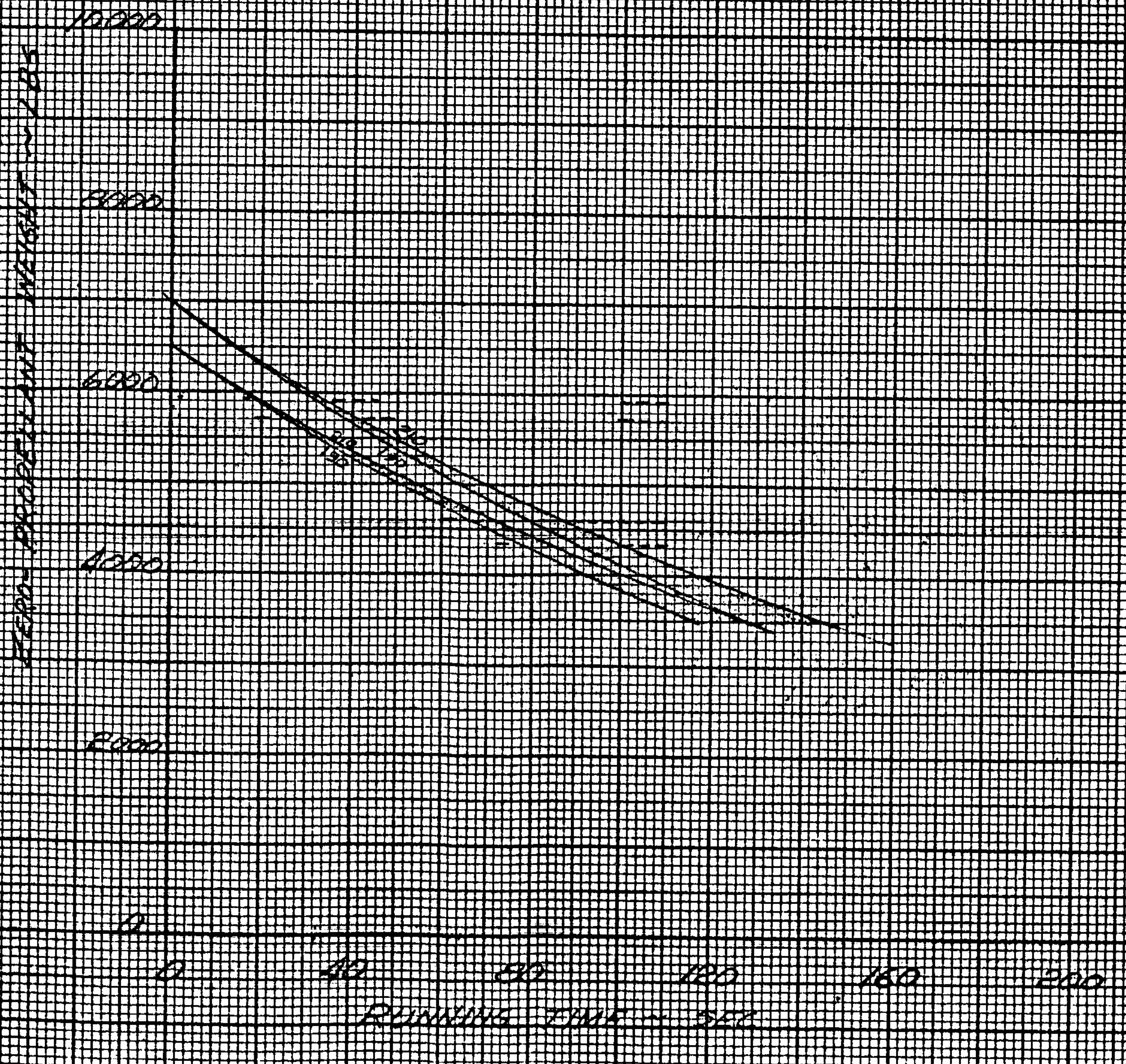
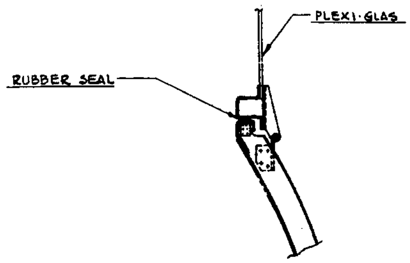
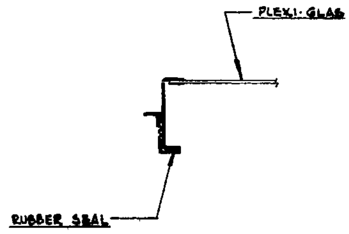


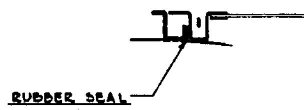
FIG. H-3



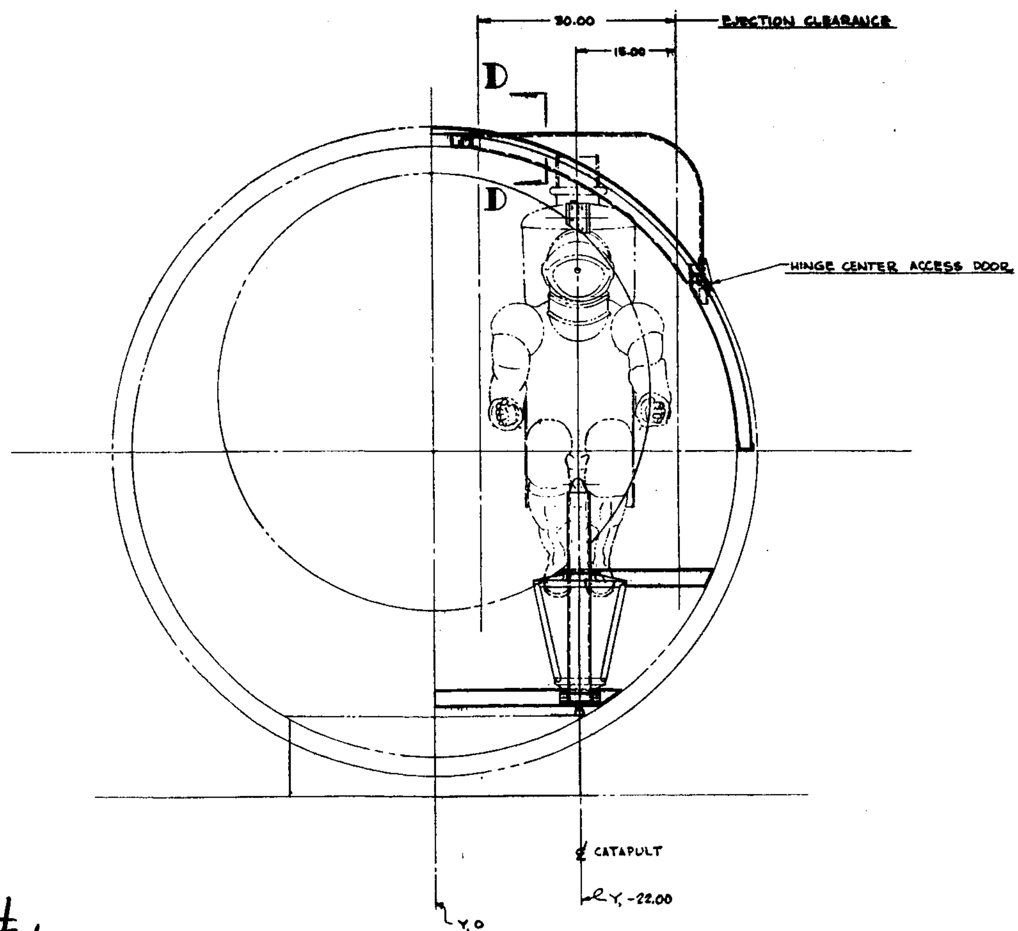
SECTION E-E



SECTION D-D



SECTION F-F



FOLD-OUT #1

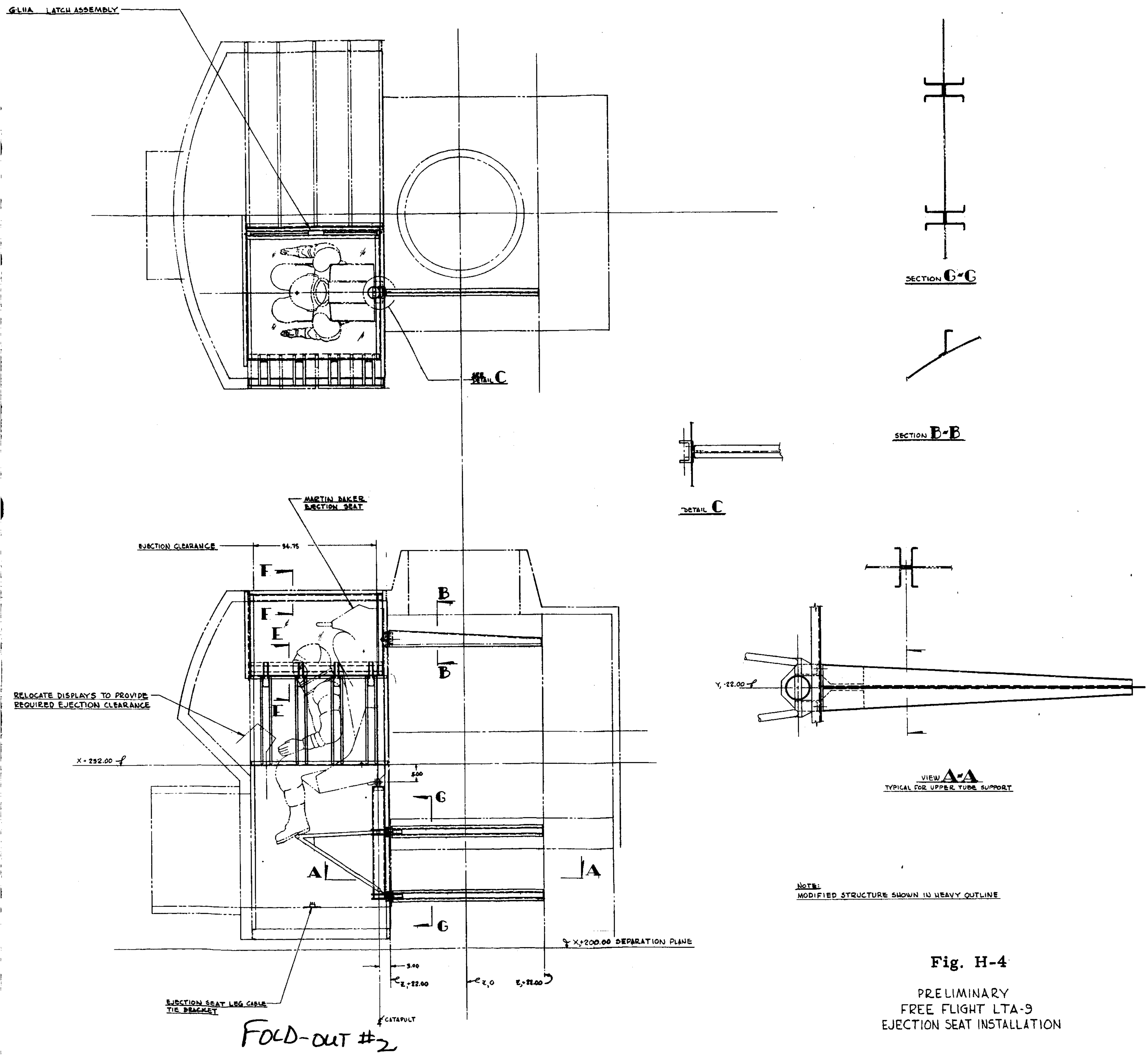


Fig. H-4

PRELIMINARY
FREE FLIGHT LTA-9
EJECTION SEAT INSTALLATION

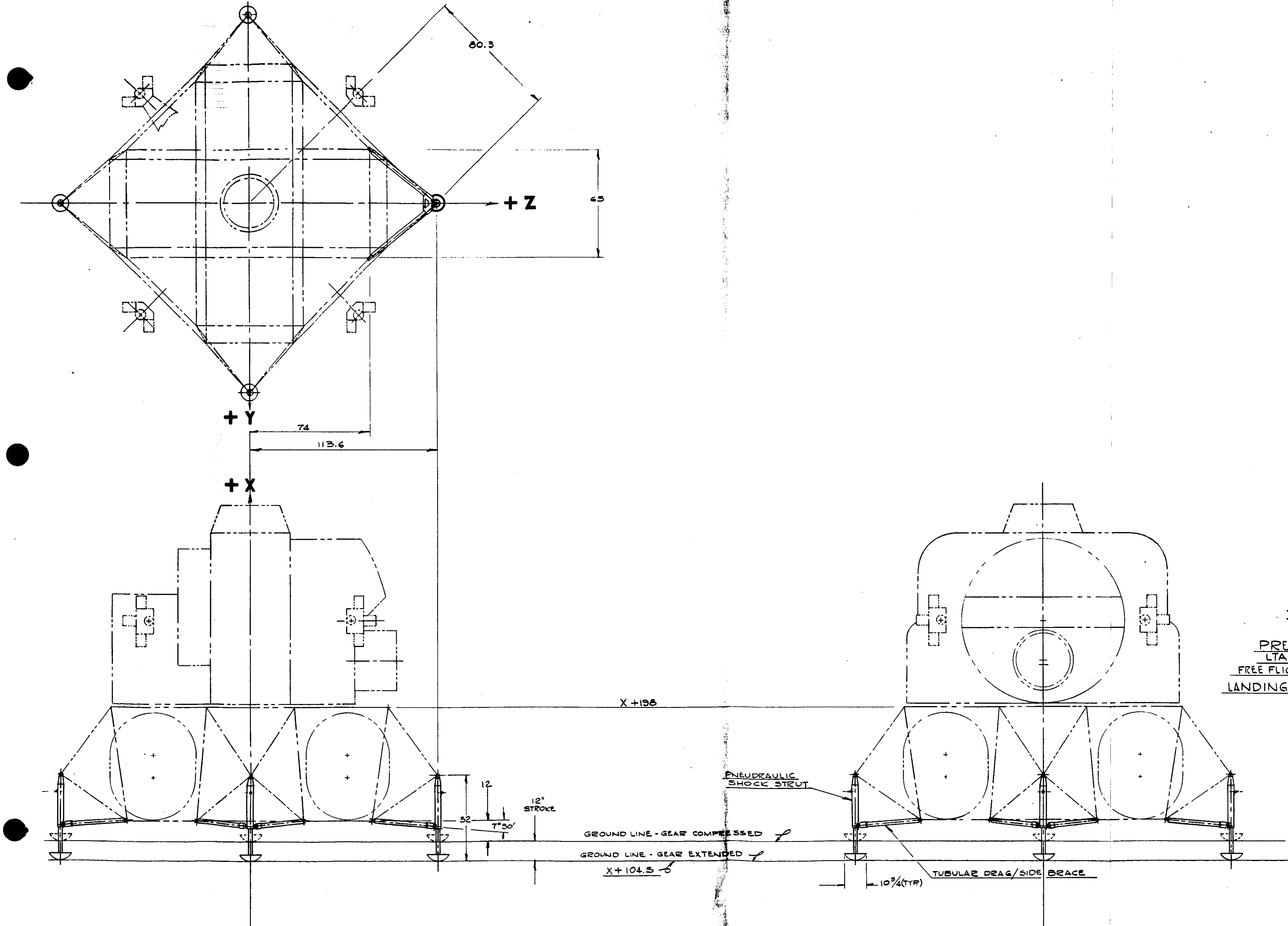


Fig. H-5

PRELIMINARY
LTA-9
FREE FLIGHT CONFIGURATION
LANDING GEAR GENERAL ARRANGEMENT

APPENDIX I-1

GROUND EFFECT PROBLEMS

A problem design area unique to the LTA-9 in the LEM program involves the effects of operating the vehicle in the atmosphere within close proximity to the ground. This condition occurs during take-offs, landings and possibly also while hovering at very low altitude. The consequence of operating within the ground effect is the introduction of additional forces and moments due to the pressure distribution about the base of the vehicle. This pressure field is generated by the engine gas flow between the base of the vehicle and the ground.

Although a considerable amount of literature exists which treat simple geometric models, it appeared to be very difficult to predict the pressure field distribution for the supersonic nozzle flow and geometric shape of the LTA-9 configuration. A small test program was therefore conducted to obtain some quantitative information of the system behavior. A 1/10 scale model was constructed to represent the interior and exterior surfaces of the descent stage as well as the base of the ascent stage including the separation plane. The descent engine was simulated by a nozzle that was sized to produce a scale thrust corresponding to 7000 pounds full scale. Since the nozzle was supplied with cold nitrogen gas at a maximum pressure of about 75 psig the geometric scale of the nozzle was adjusted accordingly. The model was equipped with a total of 18 taps to measure the pressure distribution at the base of the descent stage as well as the engine compartment and the nozzle upstream or "chamber" pressure. The location of the pressure taps is shown in Figure I-1. The pressure taps were attached to individual pressure transudcers mounted in the propellant tankage area of the model. The output of the transducers was recorded on an 18 - channel oscillograph.

Nitrogen gas is supplied to the nozzle from a pair of accumulator tanks that maintain the appropriate chamber pressure. These tanks in turn are supplied from high pressure (3000 psi) cylinders. Gas flow is controlled by opening a solenoid valve for the duration of each run. Running time is of the order of one second per run.

The entire model is rigidly attached to the nozzle which in turn is connected to the nitrogen supply system. A rigid plate simulating the ground place is supported from an adjustable stand so that both the height and the angle between the ground place and the base of the vehicle is adjustable. The overall arrangement is shown schematically in Figure I-1.

Test points were obtained for two areas of interest. The first set of runs was performed at maximum chamber pressure simulating the LTA-9 free flight. The ground board was varied from 20 to 50 inches full scale. This range covers the region encountered during landing between the time that the landing gear first contacts the ground until the gear is fully compressed. The forces on the vehicle are shown in Figure I-2 plotted for several LEM Yaw angles. As can be seen, the vehicle experiences a negative ground effect or downward force of considerable magnitude when it is in close proximity to the ground. This figure shows that if the vehicle is sitting on the ground with a clearance of 24 inches, the engine must be capable of providing of additional 2450 pounds of thrust in excess of the vehicle weight to lift the vehicle off the ground. This height corresponds to the fully extended workhorse landing gear.

Conversely, during a landing, the vehicle will be "sucked down" toward the ground with an ever increasing force unless the engine is shut down just prior to onset of ground effect. Attempting to compensate for the ground effect during landing by increasing the thrust setting is an extremely hazardous maneuver, since, if slightly too much thrust is applied, the vehicle will rise out of ground effect and accelerate upwards.

A dramatic demonstration that this negative ground effect is a real phenomenum and not an instrumentation reversal is given by fact that the model was actually capable of lifting the ground board towards the base at low heights.

Figure I-3 shows the vehicle yawing moment versus yaw angle. These curves show that the vehicle is unstable in ground effect with the trend towards neutral stability as the height above ground is increased. At very large angles there is a reversal in the stability curves. This is apparently due to the fact that at these extreme angles, the flow to the close side of the base is blocked thus reducing the negative pressure on that side and causing a restoring moment.

The combination of a negative ground effect combined with unstable vehicle moments makes the free flight LTA-9 vehicle unattractive when operating close to the ground. Although the LEM reaction control system is powerful enough to overcome the adverse moments, the additional thrust required plus the danger of being pulled into the ground dictate that special attention be given to this problem. One obvious solution would be to eliminate the ground effect altogether by using an elongated landing gear. An alternate scheme would be to employ a special take-off and landing pad with a perforated base to allow the exhaust gases to escape. This scheme has the disadvantage of requiring a precise landing onto the target pad every time to avoid the ground effect. Perhaps a more practical method to eliminate this problem is to modify the geometry of the vehicle in such a manner as to reduce the forces and moments present. Figure I-4 shows the effect of varying the stage separation gap. As the gap is increased, more external air is induced due to the ejector action of the nozzle. This increased mass flow reduces the magnitude of the negative forces. From the few test points taken under these conditions it appears that stage separation had no effect upon the magnitude of the destabilizing moments on the vehicle. If free flight was to be used, this area would be investigated further since the real vehicle has additional gaps and ports (particularly those included for the Fire-in-the Hole problem) that were not incorporated into the test model.

A series of test points were run at reduced chamber pressure to simulate the partial throttle levels associated with operating LTA-9 in a tethered mode. A model chamber pressure of 40 psig was used to simulate a full scale thrust level of about 2000 pounds. The results shown in Figure I-5 and I-6 show that although the negative forces are smaller the destabilizing moments are unchanged from the full throttle values. No satisfactory explanation to the persistency of this adverse moment has yet been found.

It should be noted that the effect of both the negative forces and the adverse moments is not as critical for the tethered configuration as it is for the free flight version. However, the effects should be known and understood by the LTA-9 test personnel since these effects do not exist in the LEM program other than during the atmospheric flights.

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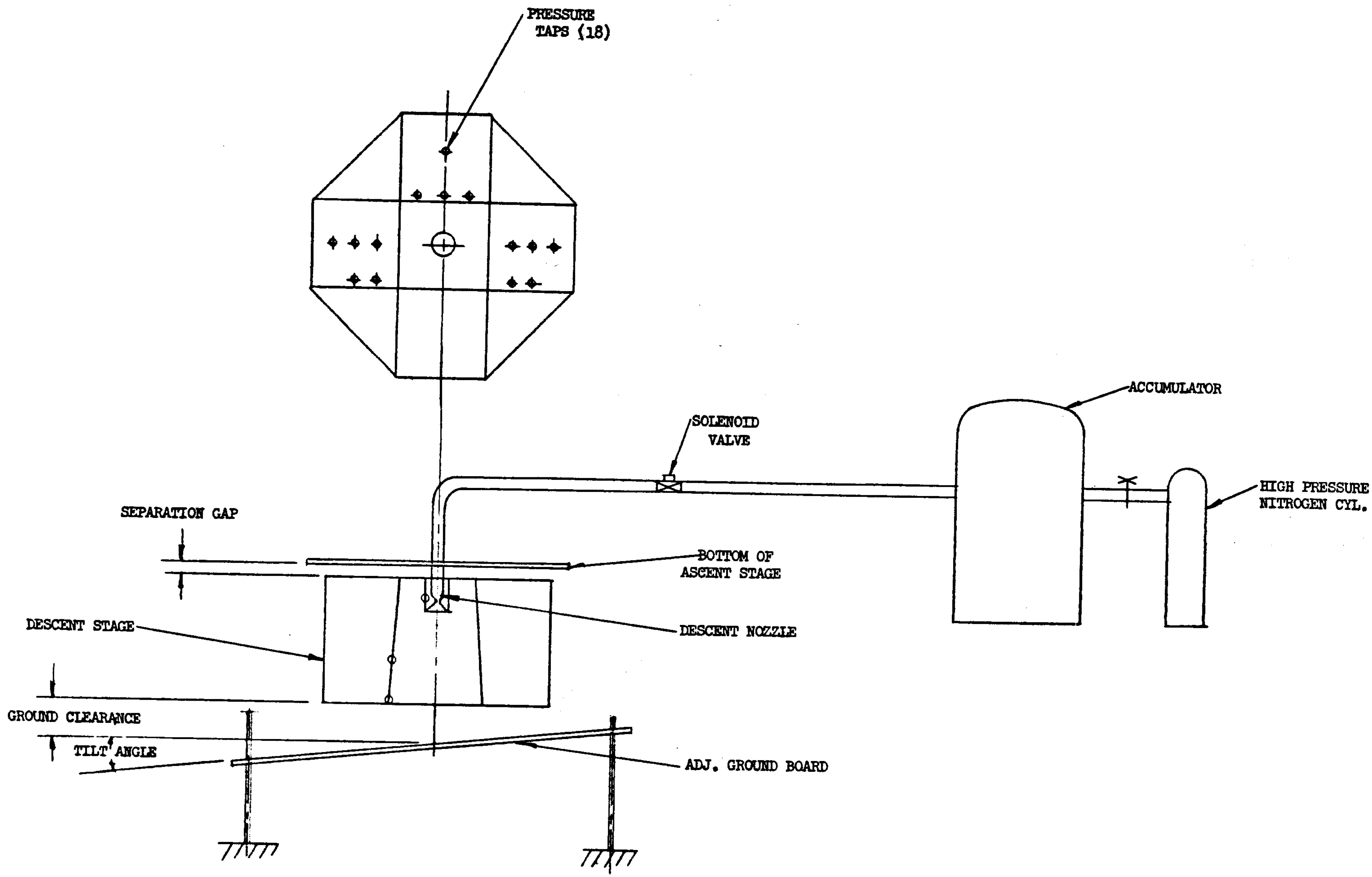
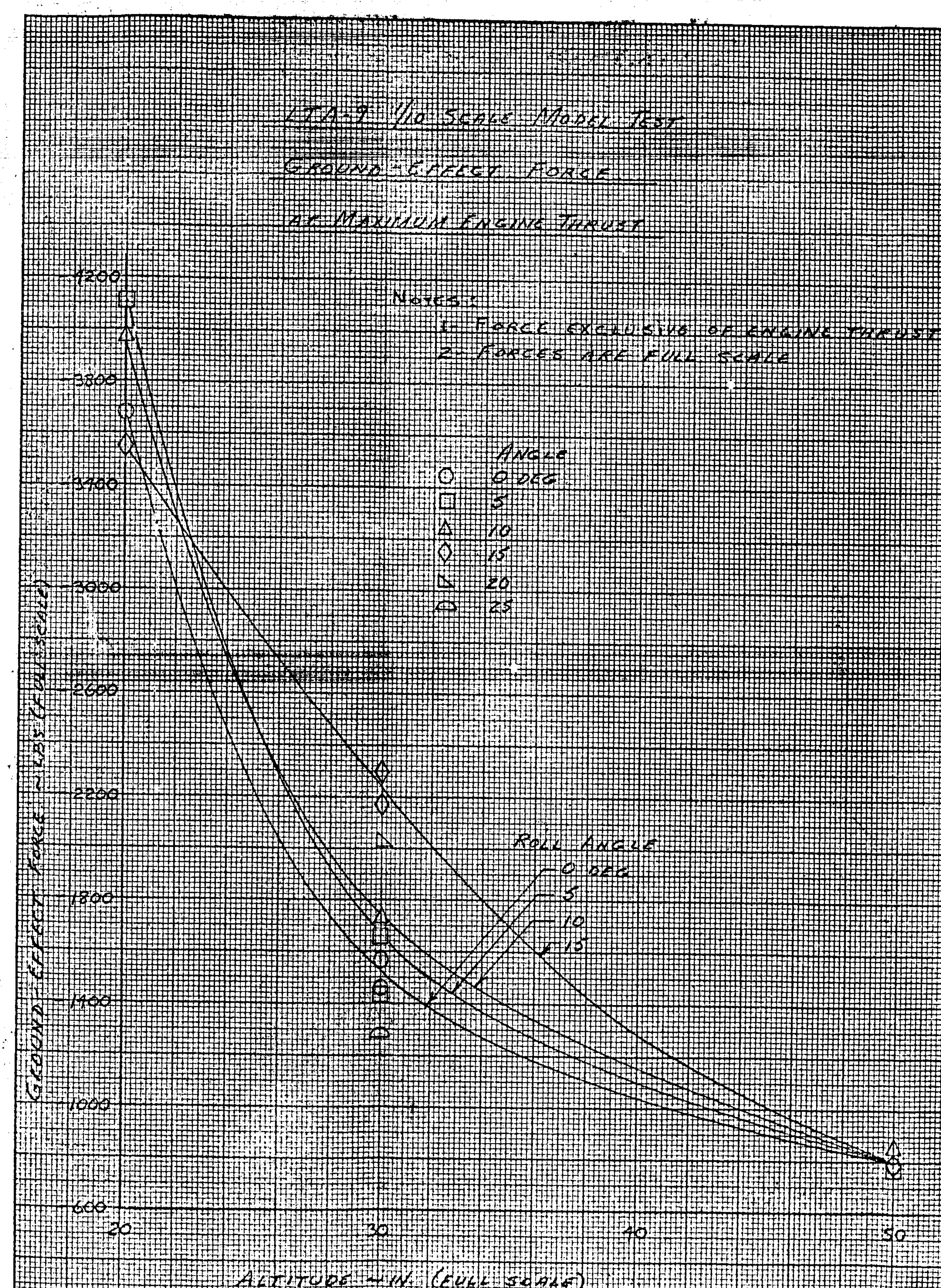


FIG. I.1

SCHEMATIC: LTA-9 1/10 SCALE DESCENT ENG. MODEL



LTA-9 1/10 SCALE MODEL TEST
GROUND-EFFECT FORCE
AT MAXIMUM ENGINE THRUST
NOTES:
1. FORCE EXCLUSIVE OF ENGINE THRUST
2. FORCES ARE FULL SCALE
ANGLE
○ 0 DEG
□ 5
△ 10
◇ 15
◺ 20
◓ 25
ROLL ANGLE
0 DEG
5
10
15
GROUND-EFFECT FORCE ~ LBS (FULL SCALE)
4200
3800
3400
3000
2600
2200
1800
1400
1000
600
20
30
40
50
ALTITUDE ~ IN. (FULL SCALE)

FIG. I-2

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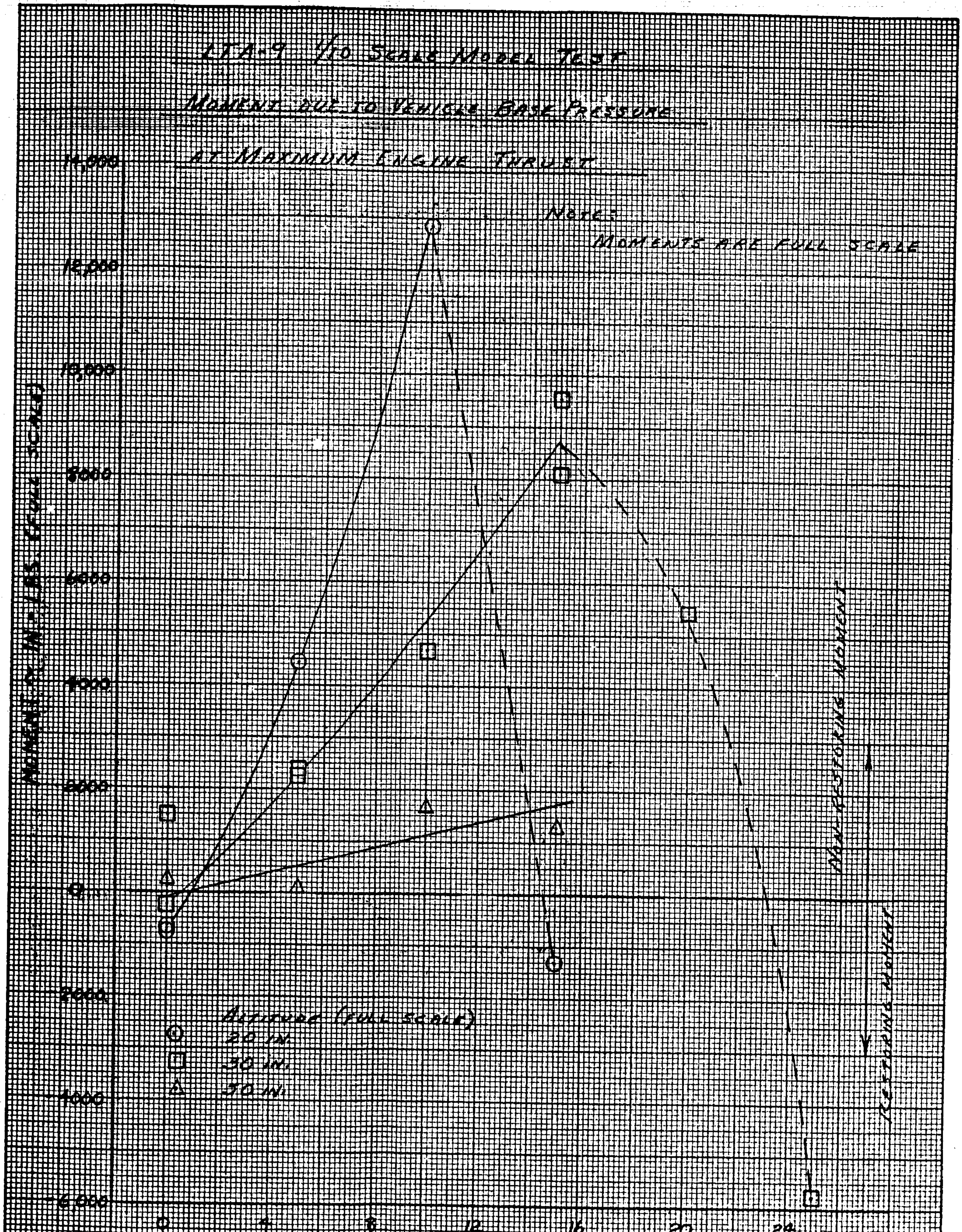

LTA-9 1/10 SCALE MODEL TEST
MOMENT DUE TO VEHICLE BASE PRESSURE
AT MAXIMUM ENGINE THRUST
NOTE:
MOMENTS ARE FULL SCALE
14,000
12,000
10,000
8000
6000
4000
2000
0
2000
4000
6000
MOMENT ~ IN.-LBS. (FULL SCALE)
ALTITUDE (FULL SCALE)
20 IN.
30 IN.
50 IN.
NON-RESTORING MOMENT
RESTORING MOMENT
0
4
8
12
16
20
24
ROLL ANGLE ~ DEGREES

FIG. I-8

6-20-63

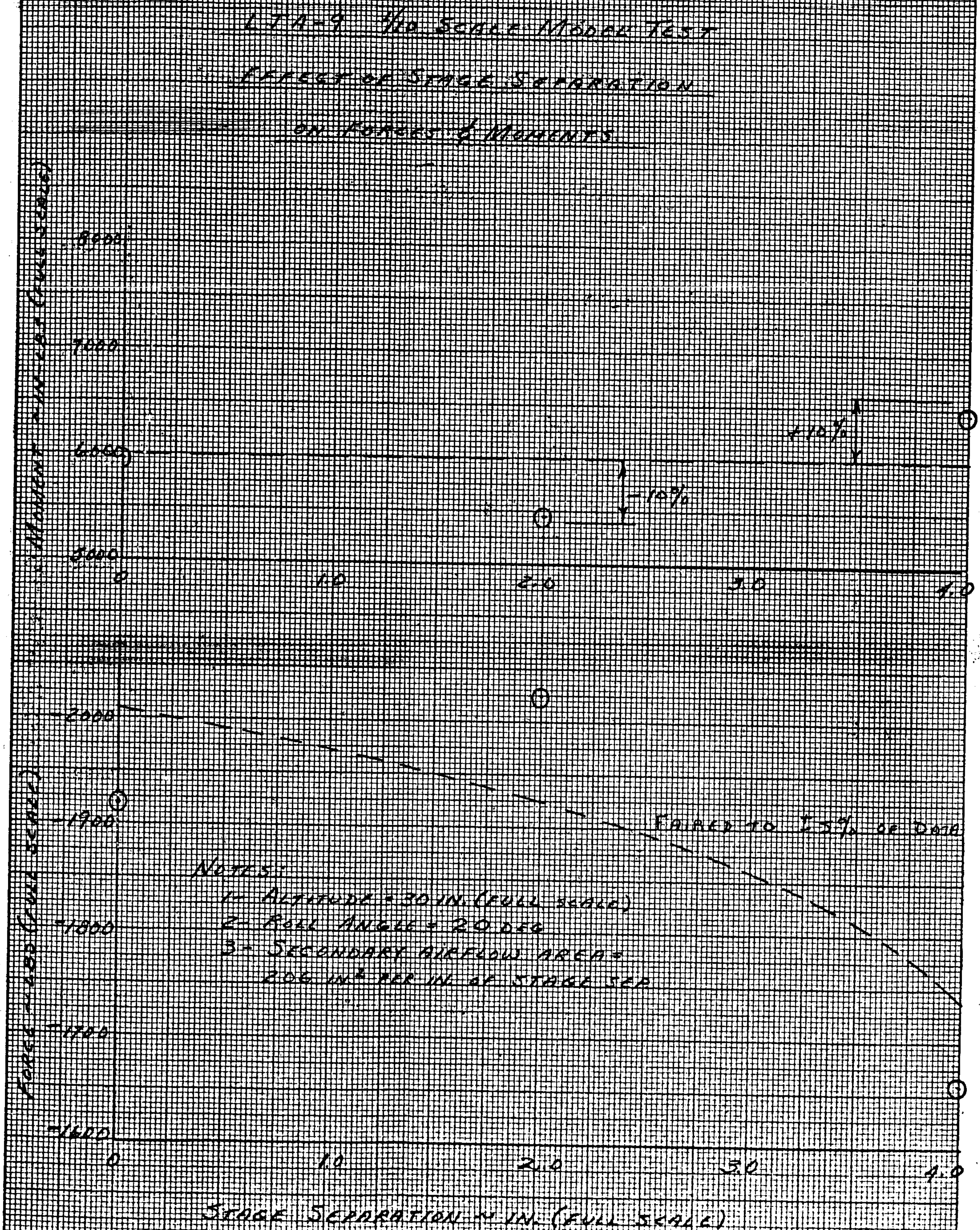
LTA-9 1/10 SCALE MODEL TEST
EFFECT OF STAGE SEPARATION
ON FORCES & MOMENTS
MOMENT ~ IN-LBS (FULL SCALE)
8000
7000
6000
5000
+10%
-10%
0
1.0
2.0
3.0
4.0
FORCE ~ LBS (FULL SCALE)
-2000
-1900
-1800
-1700
-1600
FAIRED TO ±5% OF DATA
NOTES:
1- ALTITUDE = 30 IN. (FULL SCALE)
2- ROLL ANGLE = 20 DEG
3- SECONDARY AIRFLOW AREA =
206 IN² PER IN. OF STAGE SEP
STAGE SEPARATION ~ IN. (FULL SCALE)

FIG. I-4

6-20-63

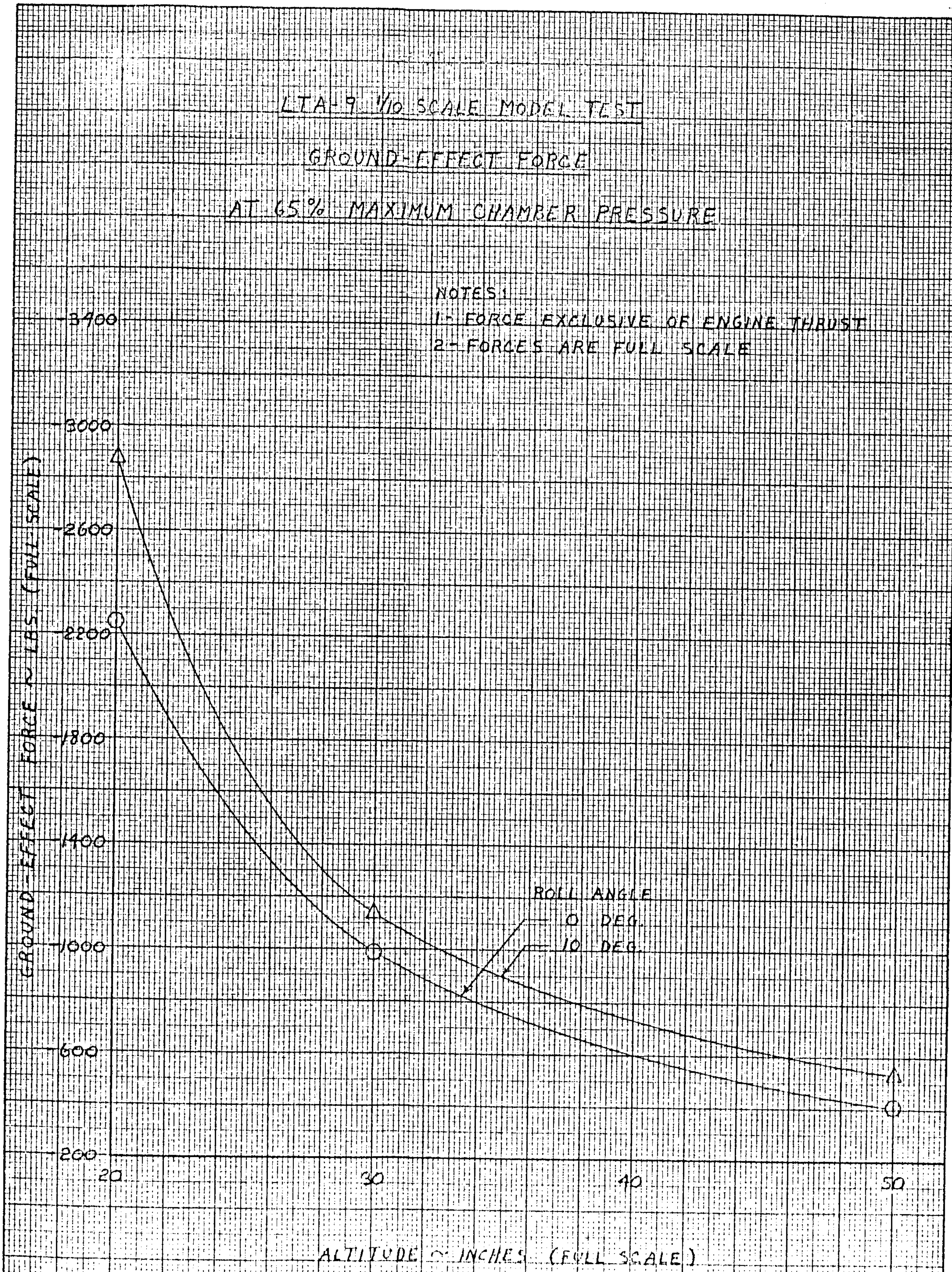
LTA-9 1/10 SCALE MODEL TEST
GROUND-EFFECT FORCE
AT 65% MAXIMUM CHAMBER PRESSURE
NOTES:
1- FORCE EXCLUSIVE OF ENGINE THRUST
2- FORCES ARE FULL SCALE
-3400
-3000
-2600
-2200
-1800
-1400
-1000
-600
-200
20
30
40
50
GROUND-EFFECT FORCE ~ LBS. (FULL SCALE)
ALTITUDE ~ INCHES (FULL SCALE)
ROLL ANGLE
0 DEG.
10 DEG.
JR
6-25-63

FIG. I-5

LTA-9 1/10 SCALE MODEL TEST

MOMENT DUE TO VEHICLE BASE PRESSURE

AT 65% MAXIMUM CHAMBER PRESSURE

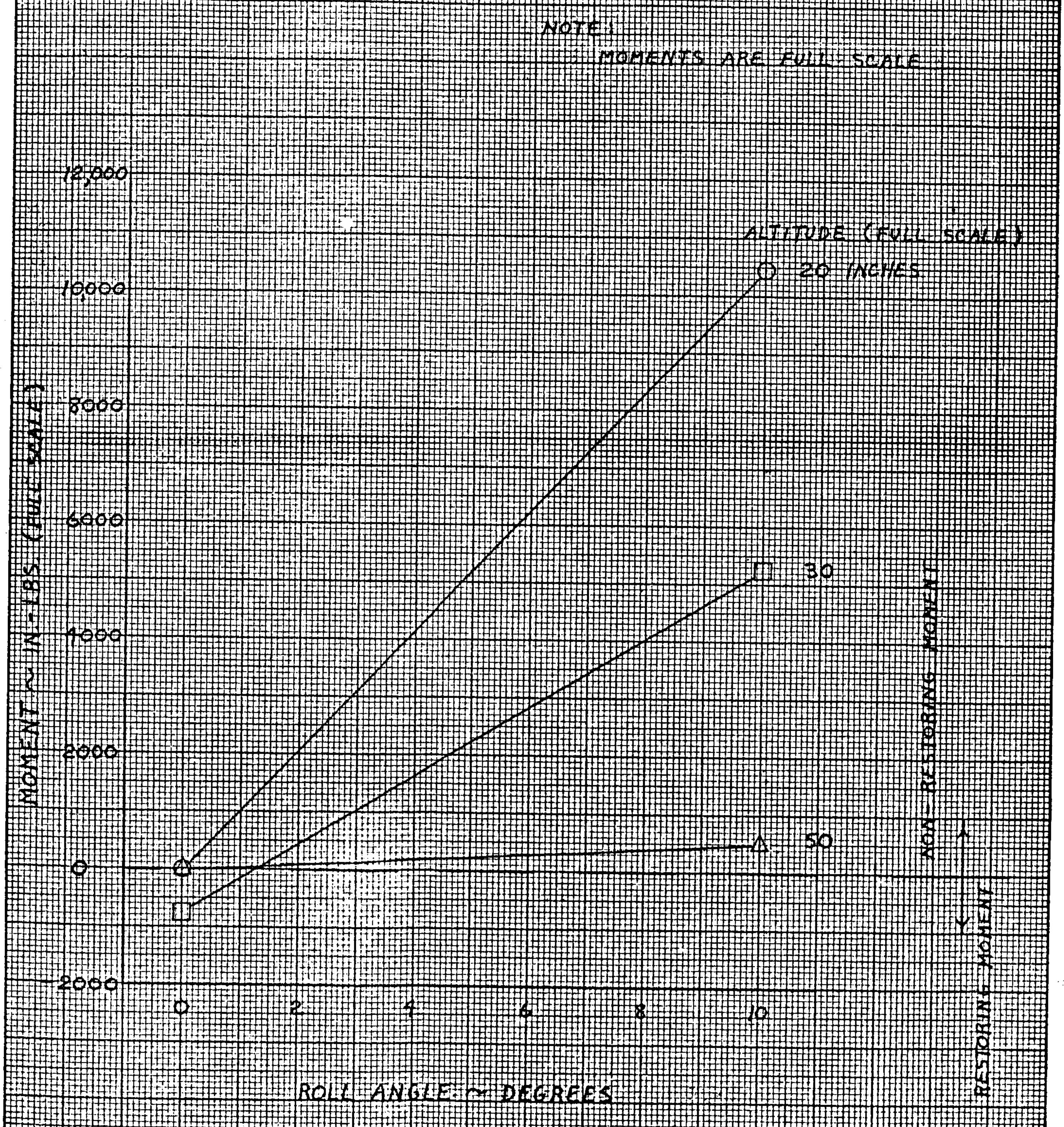

FIG. I-6

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JR

APPENDIX I-2

AERODYNAMIC EFFECTS

The aerodynamic forces and moments which the LTA-9 will be subjected to during tethered and free flight operation is another area unique to atmospheric usage of a LEM - type vehicle. This data is essential to insure that the capabilities of the LEM Flight Control System are not exceeded. In order to obtain aerodynamic data for use in the LTA-9 test and evaluation program, a series of low speed wind tunnel tests were conducted on a 1/8 scale LEM model. These tests were made at the Grumman 7 x 10 foot low speed wind tunnel during February 1963.

The model tested represented the configuration submitted during the LEM proposal. Although the presented configuration differs somewhat in the detailed arrangement of the components, it is felt that the overall aerodynamic data is still valid and applicable. The aerodynamic force and moment characteristics of the LEM are presented in Figures I-7 through I-9 for a velocity range from zero to 100 feet per second. These figures are reproduced from the LTA-9 Feasibility Study Report (Reference 8) based on data calculated from the wind tunnel results presented in the Grumman Wind Tunnel Test report 174(323-1).

The figures show that the aerodynamic forces and moments of the LEM exhibit definite non-linear characteristics along and about the body axis throughout the range of altitudes tested. However, if the flight velocities do not exceed values in the order of 20-30 fps, the magnitude of these forces and moments is low enough to be tolerable from the standpoint of achieving Flight Control System Test objectives.

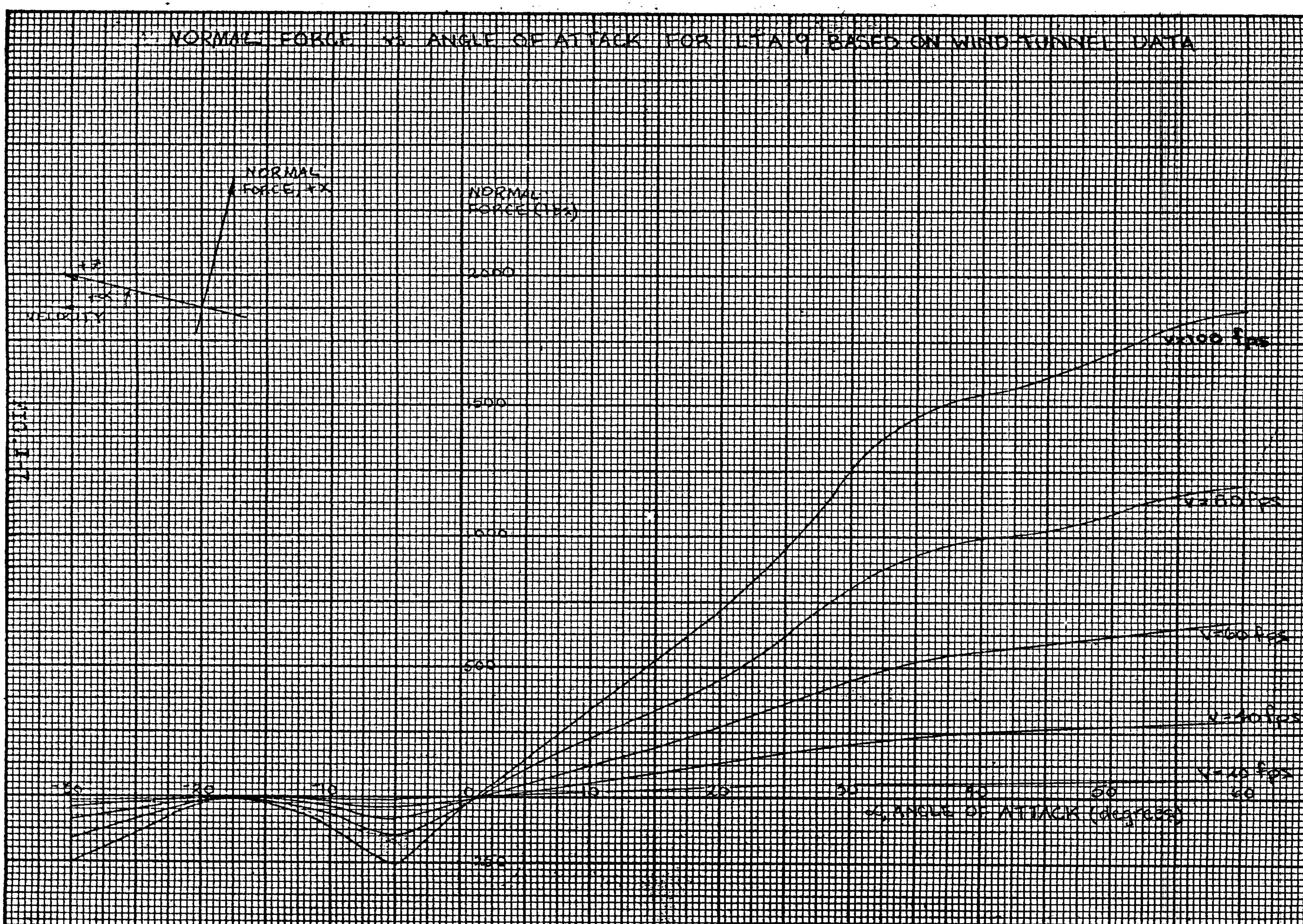
NORMAL FORCE vs. ANGLE OF ATTACK FOR LTA 9 BASED ON WIND TUNNEL DATA
NORMAL FORCE, +X
+Z
+X
VELOCITY
NORMAL FORCE (lbs)
2000
1500
1000
500
-250
V=100 fps
V=80 fps
V=60 fps
V=40 fps
V=20 fps
-30
-20
-10
0
10
20
30
40
50
60
α, ANGLE OF ATTACK (degrees)

FIG. I-7

AXIAL FORCE vs. ANGLE OF ATTACK FOR LTA-9 BASED ON WIND TUNNEL DATA

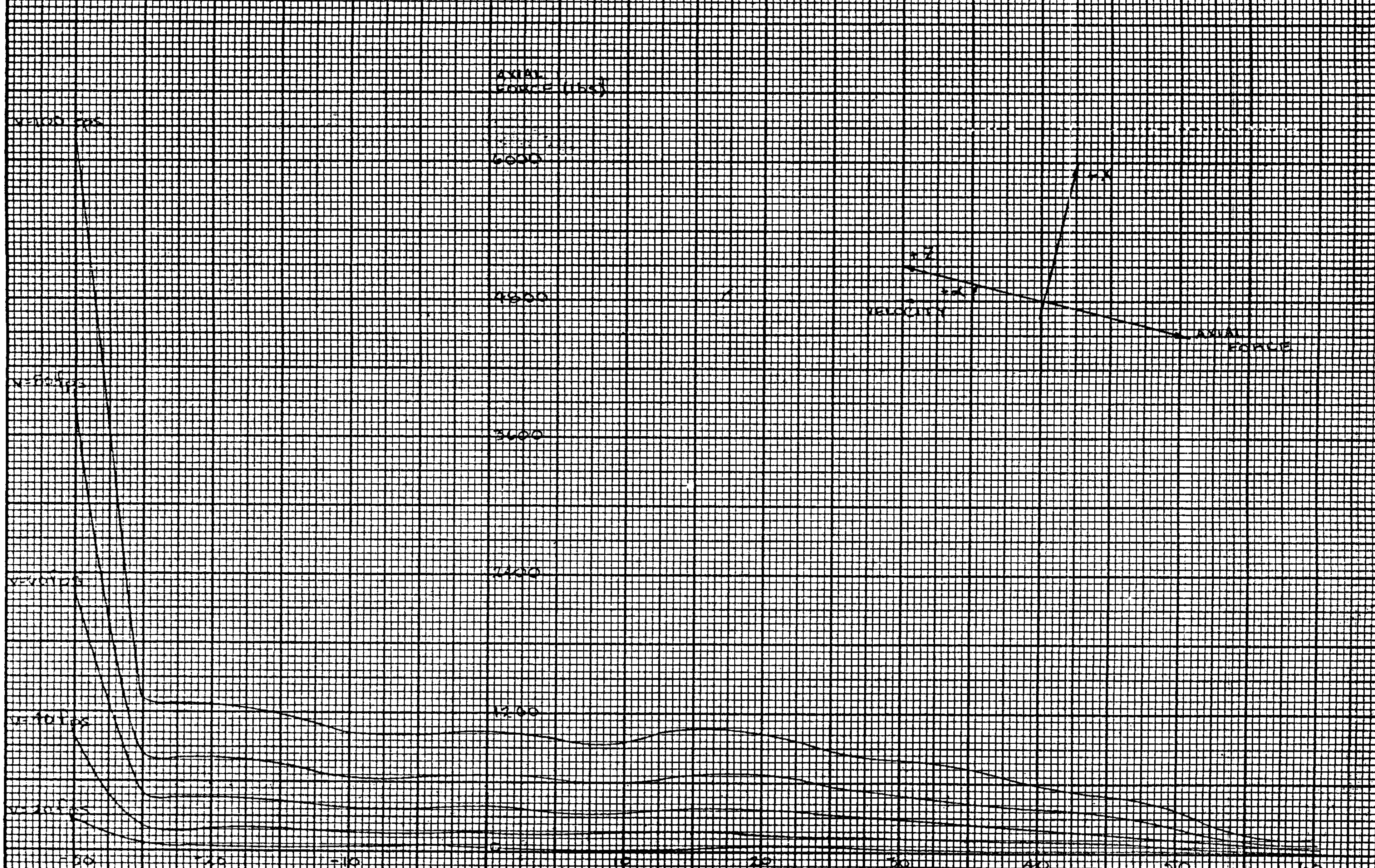

FIG. I 8

PITCHING MOMENT vs. ANGLE OF ATTACK FOR LTA-9 BASED ON WIND-TUNNEL DATA

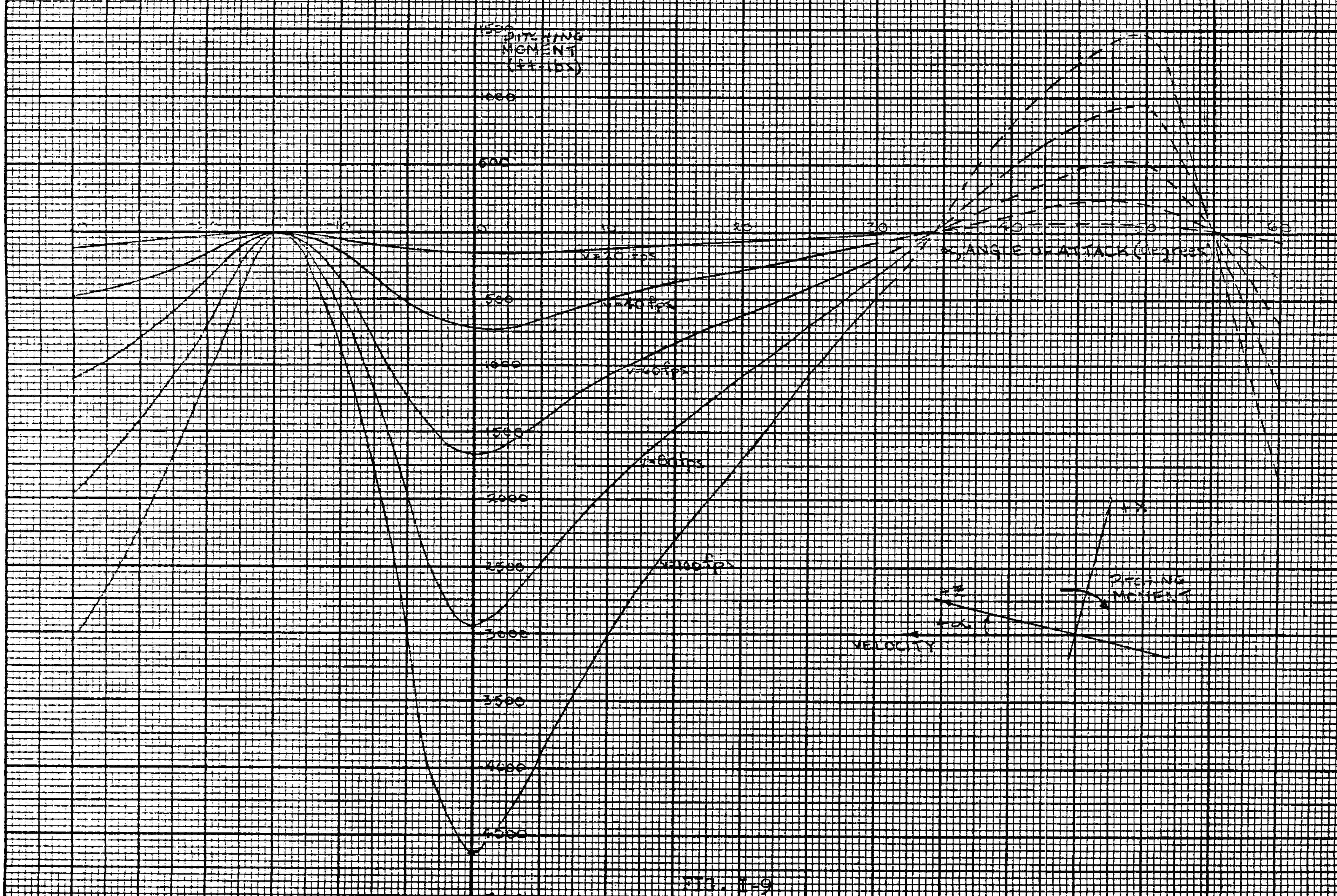

FIG. II-9

APPENDIX J

USE OF LTA-8 VERSUS AN UPRATED LTA-5 FOR RESTRAINED FIRING TESTS OF INTEGRATED SYSTEMS

J-1 INTRODUCTION

This appendix discusses the considerations involved in determining the necessity of using the LTA-8 vehicle for restrained firing tests of integrated LEM system in the WSMR altitude facility. The alternate approach would utilize an uprated LTA-5 vehicle performing the same tasks. The results indicate that using an LTA-8 to do the integrated testing, while limiting the LTA-5 to its present function of propulsion subsystem qualification article, is justified. Table J-1 summarizes the reasons why the recommended use of LTA-8 improves assuring the completely safe and successful performance of the LEM mission of manned lunar landing and return.

TABLE J-1

SUMMARY OF MAJOR ADVANTAGES TO THE LEM PROGRAM ATTRIBUTABLE TO THE USE OF LTA-8 FOR INTEGRATED SYSTEMS TEST

* Avoids compromising the actual qualification test conditions, (of a prime safety-of-flight category subsystem), as a result of performing the propulsion qualification with more subsystems than are necessary.

* Avoids compromising the integrated system test by introducing LEM equipment piecemeal, or by interconnecting early non-qualification tested subsystems.

* Earlier availability of test results from both the propulsion qualification program and integrated systems test. This approach is the only feasible way to support the first manned flight - LEM-5.

* The LTA-8 serves as a ready-made backup to LTA-5 during the propulsion qualification program.

* Use of the LTA-8 permits modification and follow-up testing of LTA-5 for Phase II propulsion subsystem qualification tests without interference in running the integrated system test program.

* Validation of subsystem vibration data, obtained during LTA-5 propulsion qualification with dummy equipment masses and detailed instrumentation, permits modification and component test requirement changes to be included in equipment which is installed in LTA-8. LTA-8 will confirm the equipment's ability to meet the environment.

* The LTA-8 is a better test article than LTA-5 for LEM flight back-up tests by virtue of having a newer and less frequently used structure as well as RCS and Propulsion Subsystem components.

J-2 DISCUSSION

In view of the preceeding table, it is apparent that using the LTA-8 for integrated testing and maintaining the LTA-5 in its present task of propulsion system qualification provides the earliest availability of test results. The schedules in Figure J-1 also show that the use of LTA-8 is the only feasible approach in which the results of integrated system testing can be incorporated into the first manned flight with LEM-5.

LTA-8 presents many other advantages to the overall LEM program. It permits the full and uninterrupted use of the LTA-5 vehicle for the propulsion qualification program including additional tests required for the Phase II modifications. The presence of LTA-8 at WSMR also serves as an excellent back-up vehicle for the propulsion qualification program in the event of a catastrophic failure to the LTA-5.

A considerable advantage in using the LTA-8 for systems testing is that the structure and all equipment "grow old" together. That is, the effects of vibrational fatigue interactions between the structure and other subsystems can be readily assessed. Whereas, if an LTA-5 vehicle is used for integrated systems tests, the basic structure will have accumulated so much running time on the propulsion qualifications prior to up-rating the vehicle for integrated use that the origin of fatigue failure cannot be determined.

It is also conceived that an integrated systems test article will be required to check out LEM modifications based on space flight feedback information. It might be advisable to have the LTA-8 installed in an altitude stand during an actual space flight. In the event that an unforseen difficulty arises during the mission, the same conditions may be simulated on this vehicle and trouble shooting under more realistic conditions to determine corrective actions to be used. For these tasks an LTA-8 vehicle is superior to a retro fitted LTA-5 because of the less frequently used structure, propulsion and RCS components.

It is important to note that the use of the LTA-8 vehicle does not require any additional test facilities, ground support equipment, or qualified LEM hardware and equipment over that which would be used on an uprated LTA-5. The only hardware savings obtained by using an uprated LTA-5 in liew of an LTA-8 is the elimination of one structure, RCS, and Propulsion subsystems.

Considering all the advantages for performing integrated systems tests using the LTA-8, the reduction in equipment and fabrication costs obtainable by using an uprated LTA-5 is insignificant compared to the increased risks and potential delays involved in this approach.

J-2.1 Current LTA-5 Test Approach

Since the outset of the LEM program, it has been recognized that a series of tests to qualify the propulsion subsystem would be required prior to the first manned LEM flight which occurs with LEM-5. The acceptance of this requirement by NASA is reflected in the LEM contact.

The Statement of Work designates the LTA-5 as the vehicle to accomplish these propulsion qualification tests.

As defined and currently scheduled and funded (See Figure 3.2), the configuration of this ground test article is limited to those subsystems that are directly related to the operation of the propulsion subsystems. Hence, LTA-5 will consist of a flight-weight LEM structural shell equipped with complete propulsion and RCS sybsystem and components of other subsystems that are directly associated with the above operation.

In the current test plan the LTA-5 qualification program would commence close to the end of the propulsion and RCS development tests conducted with the P-5 rigs. The anticipated schedule for this original program is shown as approach #1 on Figure J-1. The propulsion test programs outlined in Figure J-1 are based on the availability of three altitude test stands at WSMR.

The test operation cycles shown assumes the tests are conducted using two shifts per day/six work days per week. Under those conditions the average time to perform one propulsion qualification test one propulsion qualification test cycle is 23 calendar days. Based on the above considerations the propulsion qualification tests will be completed by the end of May 1966.

The completion date of the propulsion qualification program is important in order to meet the cut-off date to support the LEM-5 vehicle at GAEC before it is shipped to AMR. Since LEM-5 is the first manned LEM flight, it is essential that the results of the propulsion qualification runs be incorporated into this flight article before it is released from the factory acceptance tests.

J-2.2 Recommended LTA-8 Program

During the initial phases of the LEM program, before the need for repetitive integrated system testing in an altitude facility had fully crystallized, no vehicle or test article was allocated to fulfill this specific purpose. This is discussed in conjunctionwith the existing LEM ground test program in Section 3.1. Since that period, the need has been fully recognized for a program involving the repetitive testing of a complete LEM with all equipment functioning including proper operation of the Propulsion and Reaction Control Subsystems.

Grumman has designated the LTA-8 as the vehicle best suited to accomplish these integrated system tests in an altitude facility. The proposed test objectives and utilization of this vehicle are described in Section 4.

Incorporating this vehicle into the propulsion test program is shown in Figure J-1 as approach #2. The beginning of integrated system tests at altitude are shown starting in February 1966 and are based on the LTA-8 program schedule shown in Figure 3.1. The limiting factor which precludes the possibility of advancing the LTA-8 test starting points is the availability of LEM equipment for vehicle installation. Using a cycle time of 40 calendar days to perform one complete test sequence as shown in Figure 4.3, the approach #2 shown in Figure J-1 allows the LTA-8 to perform two complete LEM mission cycles of integrated testing before the LEM-5 cut-off date. Note that this approach in no way interferes with the propulsion subsystem qualification program which must be completed by this cut-off date.

The proposed combination of LTA-5 as a propulsion system qualification vehicle and LTA-8 as the integrated system restrained firing test vheicle is analogous to the aircraft industry's manned aircraft development experience. In virtually all high performance naval and military aircraft development an early prototype is assigned as the powerplant demonstration vehicle. Subsequent prototype aircraft are utilized for the flight qualification of integrated or fully equipped vehicles. A specific example is the Grumman A6A Intruder, integrated weapon system.

The No. 2 prototype is the powerplant and performance buildup and demonstration aircraft. Navigation and bombing electronics are qualified on No. 5 and No. 6 after propulsion development is well along.

J-2.3 Integrated Testing Using Uprated LTA-5

In an attempt to determine the feasibility of performing the integrated systems tests on any of the existing ground test articles, it is readily apparent that operational testing of a complete LEM with all equipment functioning and the Propulsion and Reaction Control systems operative cannot be accomplished on the present seven LTA's. The only vehicle that appears suitable for retrofitting is the LTA-5 which already uses a flight weight structure in conjunction with a completely operative Propulsion and RCS. This approach requires that the remaining subsystems be installed on the LTA-5 at the end of the propulsion qualification program. This alternative is shown as approach #3 on the schedule in Figure J-1.

In order to commence integrated system testing at the earliest possible date with this approach, only seven out of the ten engine qualification runs required would be run initially on LTA-5 before the vehicle is uprated with all the equipment.

After these initial seven propulsion runs are completed, the vehicle is laid-up in the preparation building at WSMR for installation and check out of the remaining subsystems. After this up-dating is performed, the LTA-5 is returned to the altitude stands and integrated systems testing commences. In this phase of the program, the first three engine cycles would be used to complete the propulsion qualification program as well as the integrated systems tests.

The downtime to uprate LTA-5 to a complete LEM is estimated to be about 4 1/2 months. This period is based on allowing 3 months for equipment installation plus 1 1/2 months for checkout of all equipment in the vehicle. In following this approach however, no integrated system test results will be available prior to shipment of LEM-5 to AMR.

An alternate program investigated involves the possibility of installing all equipment available for integrated testing into the fabrication of the LTA-5 vehicle and performing integrated systems testing in conjunction with the propulsion qualification work. This approach is unacceptable because un-availability of checked out equipment for some subsystems prevents completing installation at GAEC prior to July 1965. Following installation, flow check (2 weeks), checkout and acceptance tests of complete systems (6 weeks), shipping (2 weeks), and preparation and checkout at WSMR (2 months) would add to delay the starting date of LTA-5 tests from June '65 to December '65.

A further objection to this concept is that subsystems integration tests would subject all the components of the various subsystems to the potential hazards of operating a flight weight propulsion and RCS on a flight weight LEM structure without any prior tests. It is our belief that a minimum of four prop. qualification tests are required to reduce the risks associated with operating flight-type hardware under simulated flight conditions.

The schedule for this approach is shown as approach #4 in Figure J-1. After the first four runs, during which no equipment other than propulsion and RCS will be installed and checked out. This schedule shown that systems will be installed and checked out. This schedule shown that when the vehicle is ready for integrated tests only one month remains before the LEM-5 cut-off date. Since, at least three additional cycles are required (at 40 days per cycle for integrated system test) this approach does not satisfy the minimum requirements for providing a qualified propulsion subsystem for the first manned LEM space flight.

We can recall examples in at least three recent programs, Atlas, Titan, and Sparrow, where structural-propulsion coupling problems developed that were not discovered until these vehicles were well advanced in their respective flight test programs. It is the purpose of the LTA-5 propulsion qualification tests to uncover and rectify any potential interactions before a LEM test article is committed to integrated testing.

[redacted]

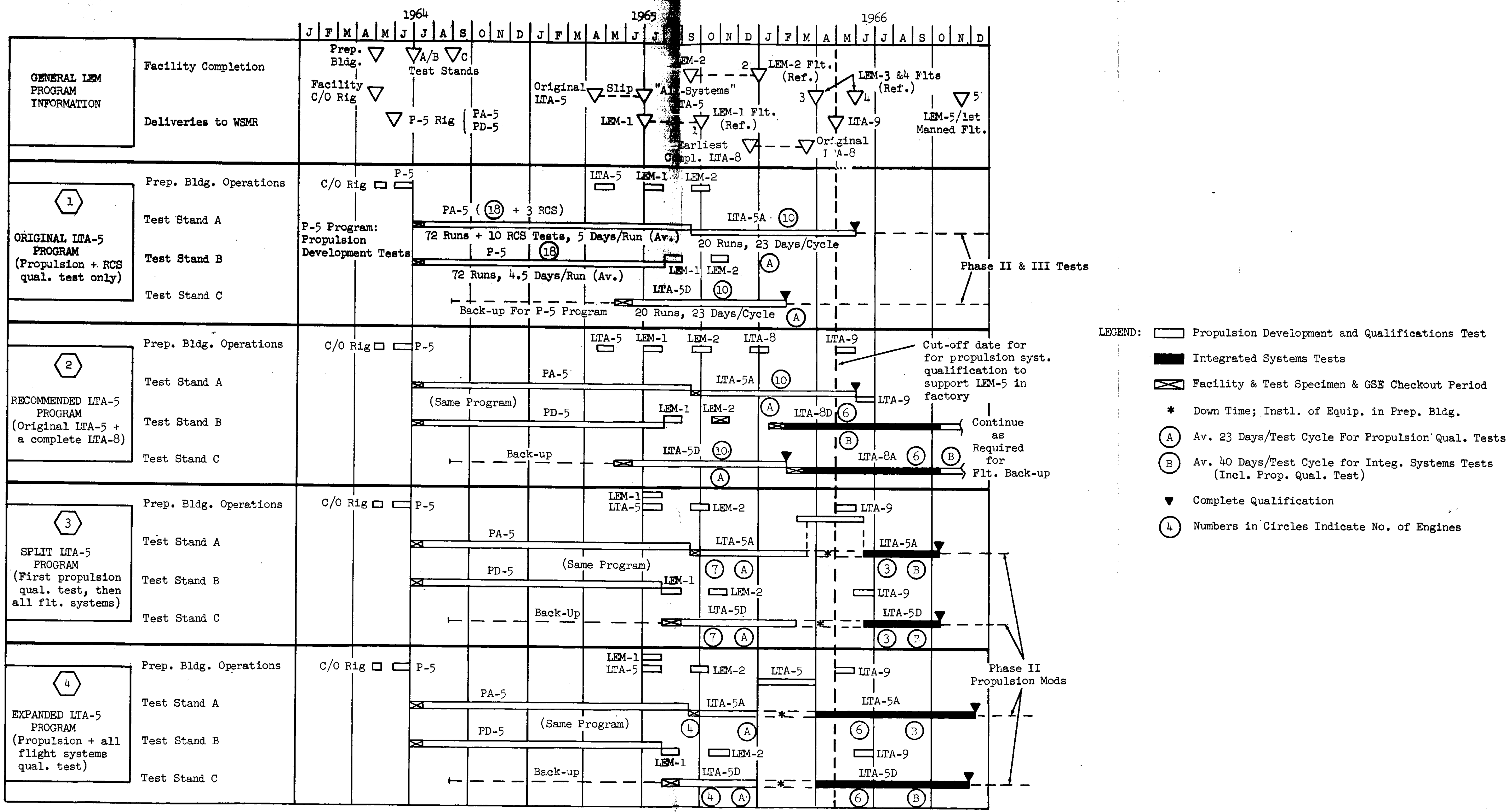

Fig. J-1 Comparison of WSMR Test Program Alternatives on Scheduling Basis

[redacted]

APPENDIX K

HELICOPTER USE FOR TETHER TESTING

It has been established in Section 5 that the limited trajectory envelope provided by the Lunar Landing Research Facility (LLRF) did not provide an adequate test of the LTA-9 Navigation and Guidance System (N & G), since this equipment required flight over the actual altitudes and ranges of the LEM terminal descent.

The possibility of achieving this performance by modifying the LTA-9 for free flight using the descent engine alone for lift is explored in Appendix H with the conclusion that only about 500 feet of altitude and 500 feet of range could be obtained, (the requirements are at least 1000 feet of range and altitude) and that serious safety problems arise.

The possibility of gaining the required performance by adding turbo-jet engines to the LTA-9 to cancel the added gravity on earth was explored in Reference 8 with the conclusion that such a program was too complicated to insure a straight forward and properly scheduled LTA-9 test program.

A third method of obtaining LEM type trajectories with the LTA-9 would be to attach the vehicle to a helicopter. GAEC has examined various aspects of this approach, and has concluded that, based on present information, it would satisfy the basic LTA-9 N & G test requirements, and offer sufficient flexibility to enhance other aspects of the test program. The investigation covered the following points:

1. Availability of helicopters with adequate performance
2. Helicopter and LTA-9 aerodynamic limitations
3. Possibility of slaving the helicopter to the LTA-9 motions
4. Operational Techniques

These points will be discussed in the following paragraphs. It was found that the Sikorsky Aircraft Corporation has already done considerable hardware testing in the areas of interest and a description of this work will be forwarded to MSC under seperate cover.

K.1 HELICOPTER LIFTING REQUIREMENTS AND AVAILABILITY

Appendix C gives a minimum all-up LTA-9 test weight of 11767 pounds not including any tether equipment. Adding to this a minimum allowance of 1500 pounds for the attaching equipment the attaching equipment the helicopter-lifted weight is 13207 pounds.

It is anticipated that any helicopter tether operations would take place at WSMR (See Section 3) where the terrain attitude is 4000 feet above sea level, and the weather altitude is equivalent to the standard tropical atmosphere. Adding to possible maximum cable length of 1000 feet, 1000 feet of actual trajectory and 1000 feet of margin to establish initial conditions, (which could be a vertical descent) the minimum required hover ceiling out of ground effect is 7000 feet.

A review of American helicopters indicates that both the Vertol Chinook*and the Sikorsky (S-64) meet this requirement; the Chinook providing 13670 pounds of load capability and the S-64 providing 16480 pounds of load capability at the altitude and temperature indicated above. The Chinook will be in the Army and Marine inventory starting in FY 63 and the S-64 will be in the Army inventory in FY 64 and it is assumed that either helicopter could be bailed for LTA-9 testing.

K.2 HELICOPTER AND LTA-9 AERODYNAMIC LIMITATIONS

Wind tunnel tests of a typical LEM configuration indicate that aerodynamic moments large enough to compromise the Flight Control System (FCS) tests can develop at speeds of about 18 ft/sec, and that the entire LTA-9 control power would be needed to trim out the moments developing at a velocity of 37 ft/sec. Hence it is reasonable to assume that tests would be limited to speeds below this figure.

As the LTA-9 approaches a hover the helicopter must also hover in the aerodynamic sense if there is no wind, and this introduces a second aerodynamic limitation, i.e., possible rotor downwash effects on the LTA-9. The severity of the problem is indicated by Figure K-1 which shows the variation in dynamic pressure at various radial and axial positions below a hovering S-64. The figure was obtained by scaling the test results presented in Reference K-1. The initial gradient across the disc is very steep, varying from 7 to 126 percent of the momentum value, and although the gradient quickly subsides, the average downwash at the 48 foot point is still 63 ft/sec.

In order for this core of high velocity air to dissipate to 18 ft/sec, sufficient viscous energy exchange must occur with the surrounding air so that the original downwash core diameter of 53 feet increases to about 500 feet. While this must happen ultimately, and may occur within sufficient distance to use a long cable tether, a simpler means of avoiding the helicopter downwash would be to fly forward at very low speeds.

An analysis using momentum theory results in a curve of Figure K-2 giving the length required at each speed so that the downwash core falls behind the LTA-9. It will be noted that a 300 foot cable provides minimum speeds of about 10 ft/sec. 100 feet less cable raises the minimum speed to 14 ft/sec., while 100 feet more cable lowers the minimum speed to 9 ft/sec. While the 300

* with the T-55-L3 turbines

foot cable length probably would not be sufficient to permit adequate downwash dissipation in pure hovering flight, it provides an adequate velocity range below the 18 and 37 ft/sec limits discussed previously. It also offers the possibility of using winds in range from 10 to 15 ft/sec to achieve a hover relative to the ground when flying up-wind and achieving ground speeds up to 33 ft/sec when flying downwind.

K.3 PROSPECTS OF SLAVING THE HELICOPTER TO THE LTA-9 MOTION

The previous section showed that the aerodynamic limitations of tethering the LTA-9 to a helicopter could be avoided if a cable of the order of 300 feet were used and air speeds were kept in the range from about 10 to 37 ft/sec. This would permit use of a simple carry technique in which the LTA-9 was suspended on a whiffletree at the end of the cable and descent engine was limited to small tilt angles where the horizontal component of thrust could be compensated for by the pilot.

Review of the current helicopter technology has indicated that it would be feasible to slave the helicopter to the LTA-9 motion by using angle and acceleration inputs measured at the top of the whiffletree (Reference K-2). Another development of interest is a system already flight-demonstrated by the Sikorsky Division of United Aircraft in which the helicopter is guided vertically by the tension in a line held by an operator on the ground and horizontally by the angle between the line and a vertical reference in the helicopter. This equipment makes extensive use of ASW Sonar transducer tethered experience and hardware, and is adaptable to the S-64 helicopter.

A qualitative appraisal of the degree either of these systems could follow the LTA-9 may be gained from the following considerations:

1. The helicopter thrust vector would be roughly 6 times larger than that of the LTA-9. Hence for constant throttle settings the available helicopter tilt acceleration could be well below the LTA-9 value while still providing the necessary horizontal acceleration due to thrust tilt.

2. The LTA-9 thrust response to a sharp throttle change will be higher than that of the helicopter. Hence sudden throttle changes while the LTA-9 is tilted could introduce horizontal and vertical accelerations approaching a step-input. This represents an inherent limitation of the helicopter tether system, but should not be very constrictive in practice, since GAEC simulator studies indicate that pilot throttle motions are usually smooth and not too rapid.

3. The speed range of interest (from about 10 to 37 ft/sec is low enough so that long periods of high horizontal acceleration are out of the question. Hence there is no risk of approaching helicopter performance limitations.

4. It should be noted that the cable bending problems associated with gantry tether discussed in Appendix D will also apply to a helicopter cable tether. Hence the analysis results shown in Figure D-5 are also applicable. These curves show that if a cable weight of 1.0 lbs/ft (breaking strength 55000 pounds) is chosen the cable frequency is .95 cps a value adequately removed from the LTA control and fuel sloshing frequencies.

K.4 OPERATIONAL TECHNIQUES

GAEC has reviewed the various operational techniques for the LTA-9 helicopter tether system and suggests the following approach as one which provides the required testing with minimum hazard. It requires the LTA-9 to be equipped with a supporting tether cable about 300 feet long and a second cable passing through an escape hatch above the pilot to provide an escape means in the event that an emergency occurs and the LTA-9 must be dropped.

Lift-off would be accomplished by hovering the helicopter over the LTA-9 and slowly taking up on the cable. A pretorqued drum could be used to increase the tension in the cable as the end was reached thus avoiding sudden shock loads at lift-off.

After climbing to about 3000 feet the helicopter would set up the initial horizontal velocity for the lunar trajectory. Next, the FCS system would be checked functionally, followed by descent engine start and adjustment to the initial thrust/weight ratio (lunar) of about 1.0. Finally the helicopter servo systems would be switched to operate and the test descent rate established.

The test would terminate when the air speed fell below about 10 ft/sec or when the rocket exhaust impingement on the ground presented difficulties. It is possible that, after gaining experience with the system, landings on a prepared surface could be attempted, provided approaches were into steady winds slightly above 10 ft/sec.

Normal recovery procedure would require the helicopter to come to a hover and slowly descend until LEM touchdown occurred. The LTA-9 pilot would then disconnect the tether and safety cables.

K.5 COMMENTS AND RECOMMENDATIONS

The previous discussion suggests that the full terminal descent trajectory could be achieved for LTA-9 system test with little expansion in the helicopter state-of-the-art. The cable angle and tension system developed by Sikorsky would represent a logical starting point for a minimum development effort system, but it has not been firmly established that the following capability thus provided would meet the LTA-9 requirement. Alternate approaches would be to use a servo controlled cable-winch together with the angle measurements at the helicopter and acceleration measurements at the LTA-9 or the Reference K-2 system which includes both a cable-winch in the helicopter and angle and acceleration measurement at the bottom of the cable.

In the case of the Sikorsky angle and tension system GAEC has been advised informally that a flight verification of the achievable performance could be obtained in less than three months using hardware components and aircraft currently available at the Sikorsky Plant together with a LTA-9 mockup that could be provided by Grumman. It is recommended that such a program be examined further, since a successful conclusion would permit a generous time period for delivery of the actual LTA-9 equipment while avoiding a new system development.

APPENDIX K REFERENCES

K-1 McKee, John W. and Naeseth, Roder L., "Experimental Investigation of the Drag of Flat Plates and Cylinders in the Slipstream of a Hovering Rotor" NACA TN 4239, April, 1958

K-2 "Preliminary Engineering Proposal for a Lunar Landing Aid and Rendezvous Docking System" Report AD-645(P) Astronics Division Lear Siegler, Inc. 11 February 1964

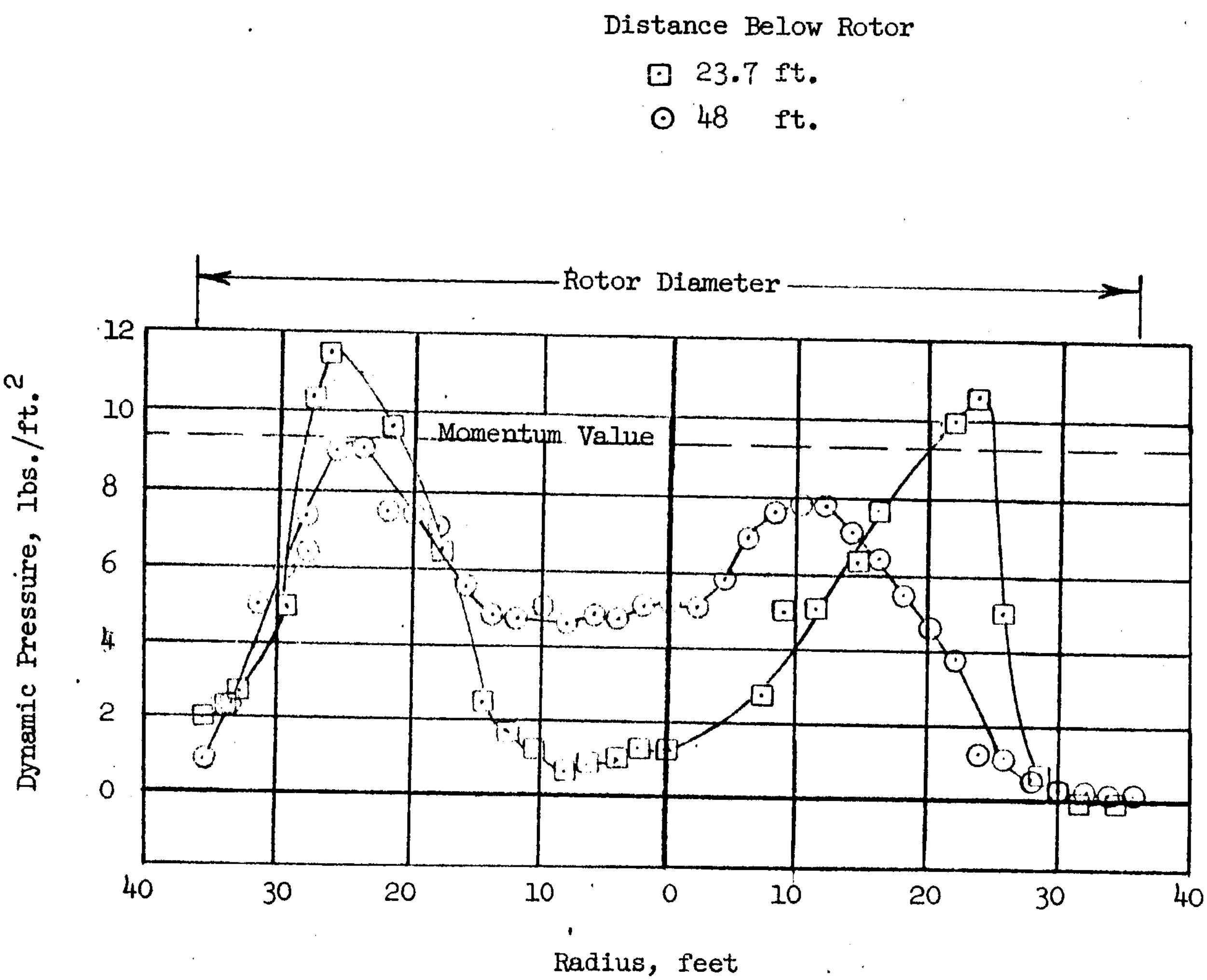

Figure K-1. Downwash Variation Under a Hovering S-64 Helicopter

CABLE LENGTH VARIATION WITH HELICOPTER SPEED FOR LTA-9 FORWARD OF DOWNWASH

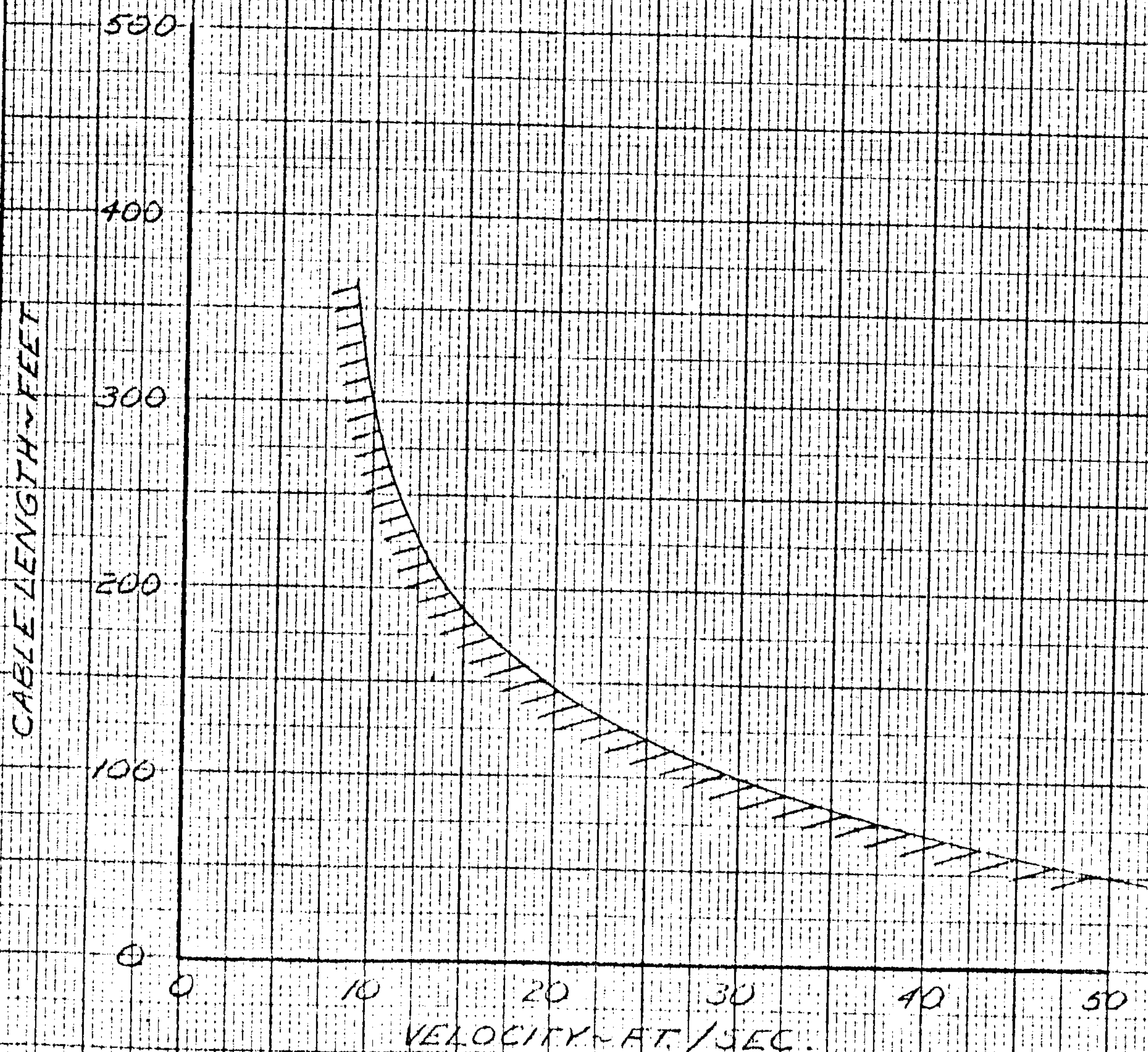

Figure K-2.